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ON PLASMA PHYSICS AND APPLICATIONS
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Atmospheric Plasma Immobilization of Antimicrobial Zeolite Loaded Silver Nanoparticles on Medical Textiles

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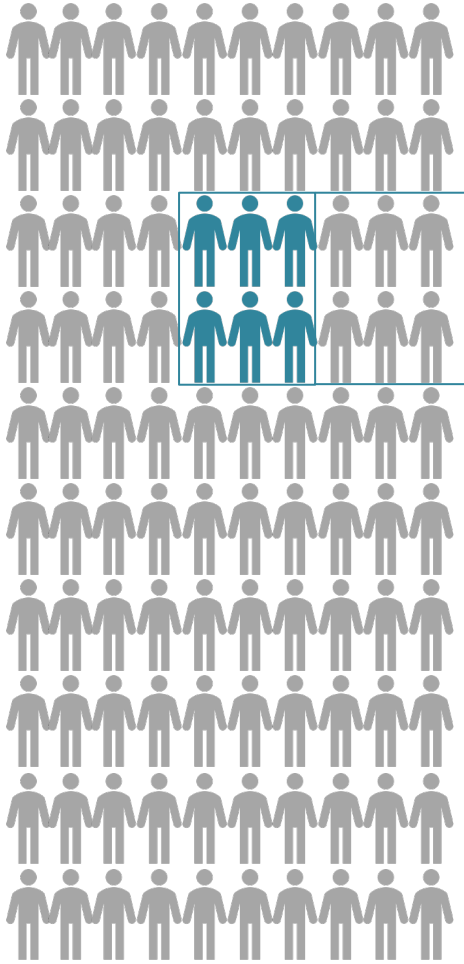
PROJECT "PLASMAMED - Bionanocomposite coatings with controllable antibacterial activity using atmospheric-pressure plasma deposition" PTDC/CTM-TEX/28295/2017 financed by FCT, FEDER, and POCI in the frame of the Portugal 2020 program.

Introduction

Healthcare-associated infections (HAIs) - statistics

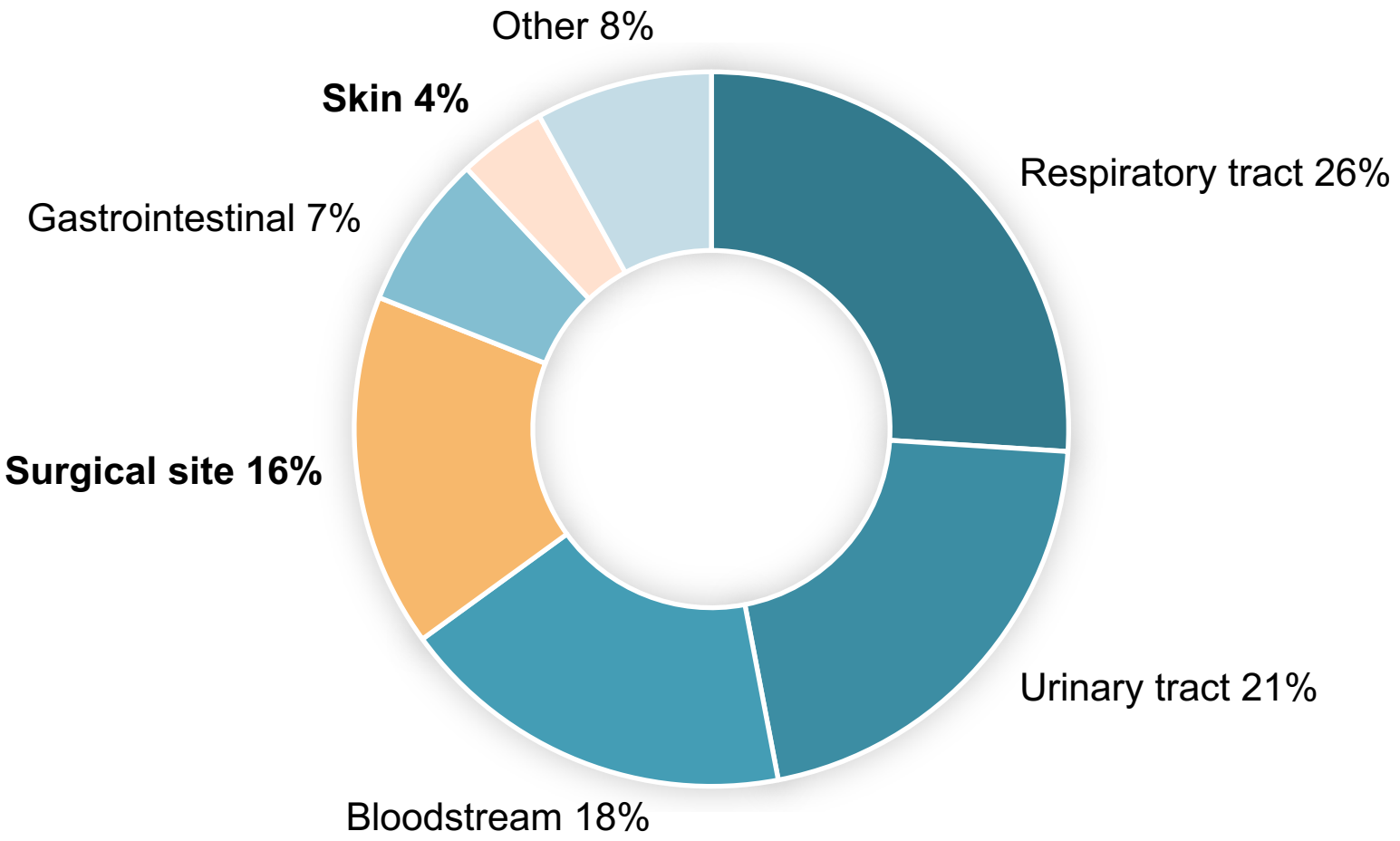


6% of the patients in European hospitals are infected at least 1 HAI

European Centre for Disease Prevention and Control Website Data

Introduction

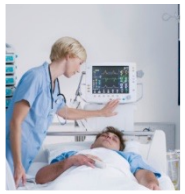
Healthcare-associated infections (HAIs) - statistics



European Centre for Disease Prevention and Control Website Data

Introduction

Healthcare-associated infections (HAIs) - main concerns



Health risk

Health costs

Antibacterial resistance

New antibacterial materials are needed

Introduction

Metal Nanoparticles

Ag | Cu | ZnO

Unique Chemical and Physical Properties

Antimicrobial | Antiviral | Anti-inflammatory

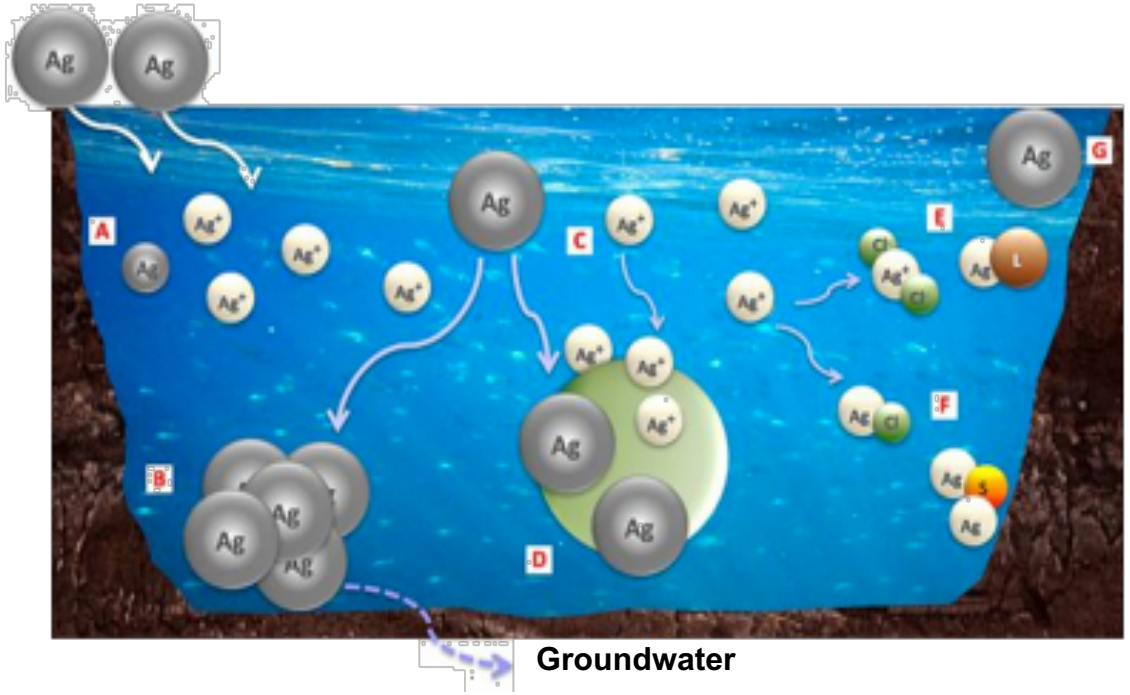




Introduction

AgNPs employment - main disadvantages

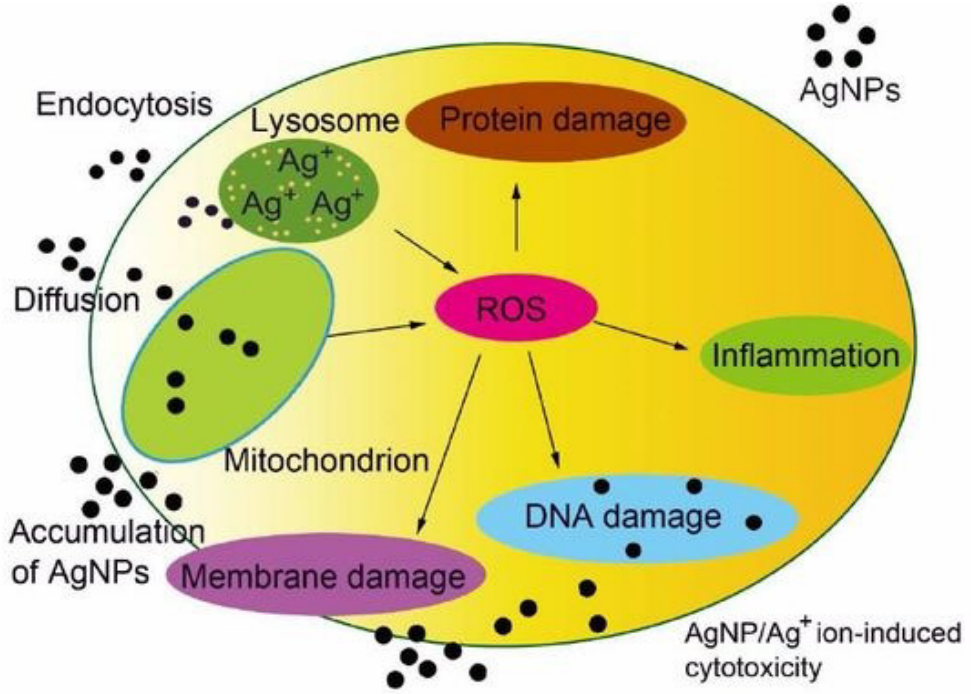
- The release and fate of silver nanoparticles into the environment



Introduction

AgNPs employment - main disadvantages

- AgNPs can display cytotoxicity and genotoxicity in human body

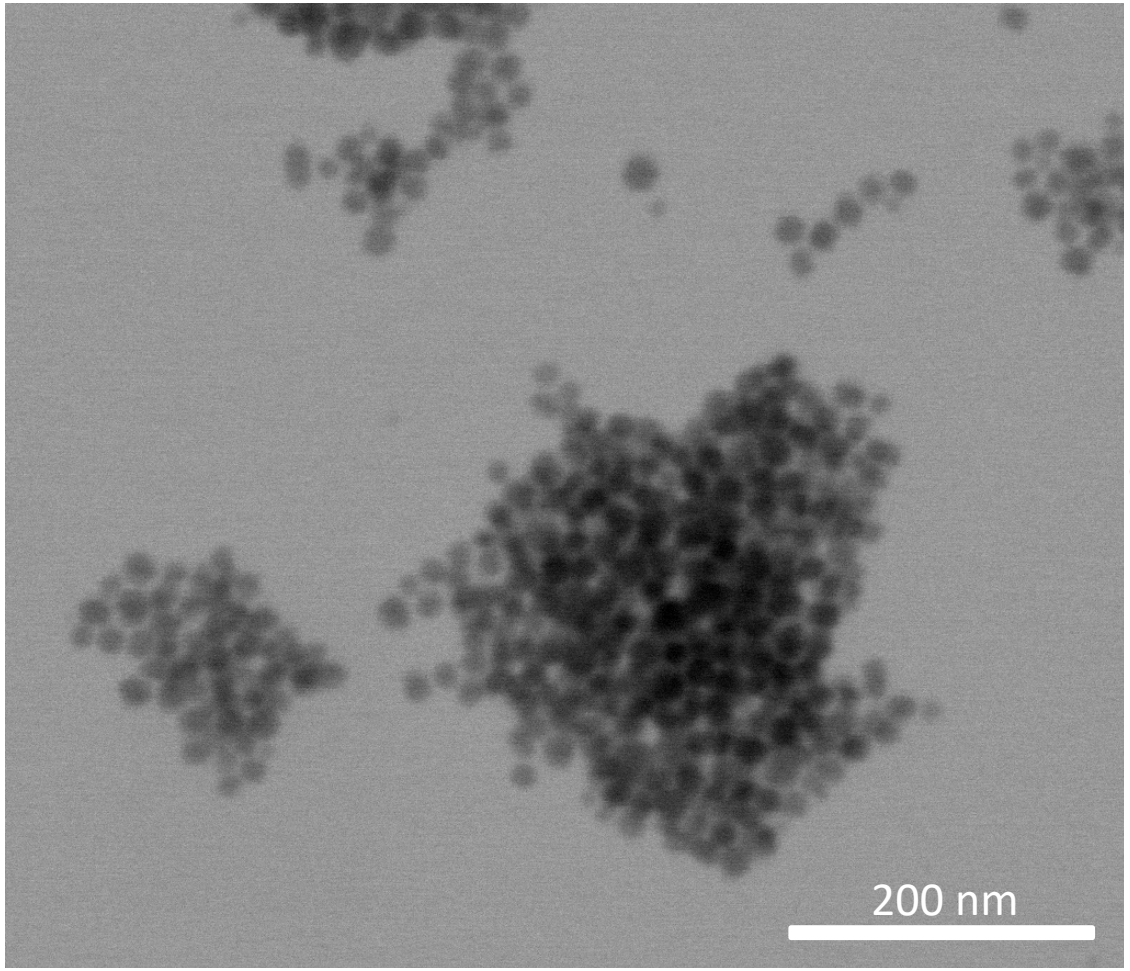


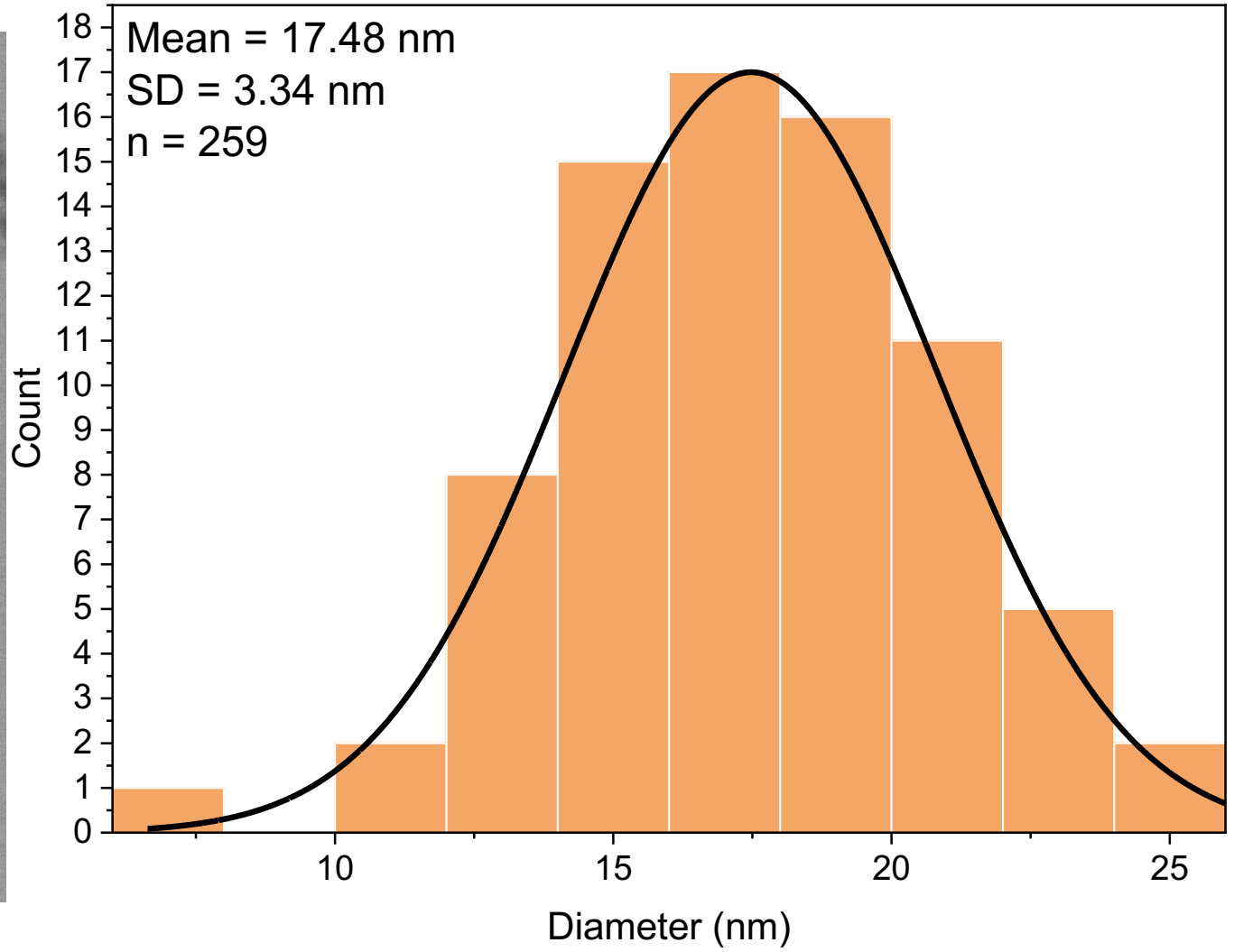
Workflow

1. Silver Nanoparticles (AgNPs) dispersions
2. AgNPs immobilization on Zeolite
3. Enzyme Immobilization on Zeolite
4. Biopolymer addition: Alginate (PES) e Chitosan (CO)
5. AgNPs + Enzymes + Polymers on Zeolites
6. Plasma deposition on textiles

Silver nanoparticles

AgNPs (STEM) and histogram size distribution



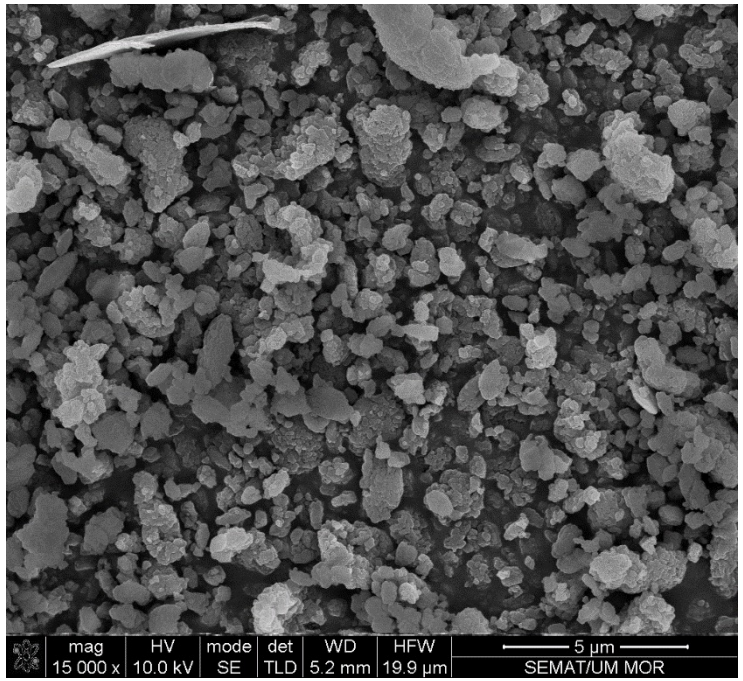


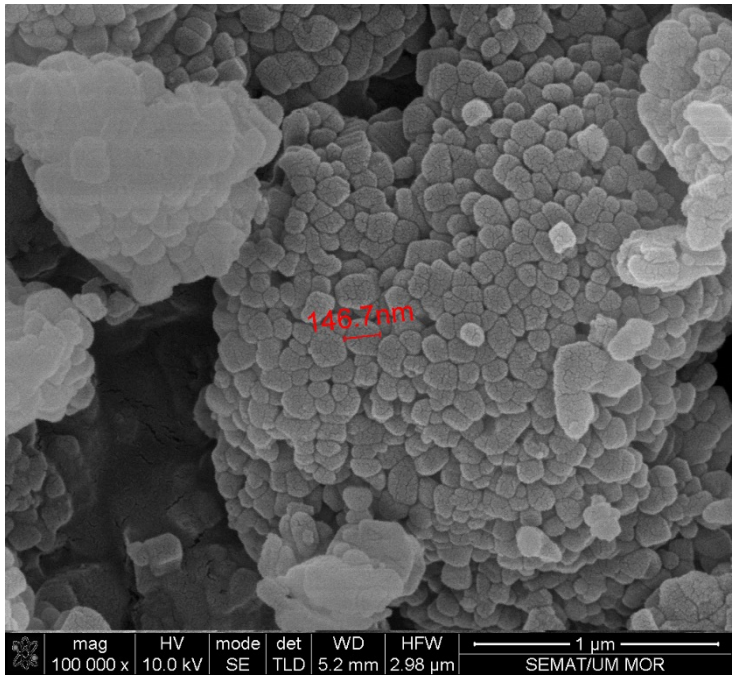
ZEOLITES

ZEOLITES (Mordenite)

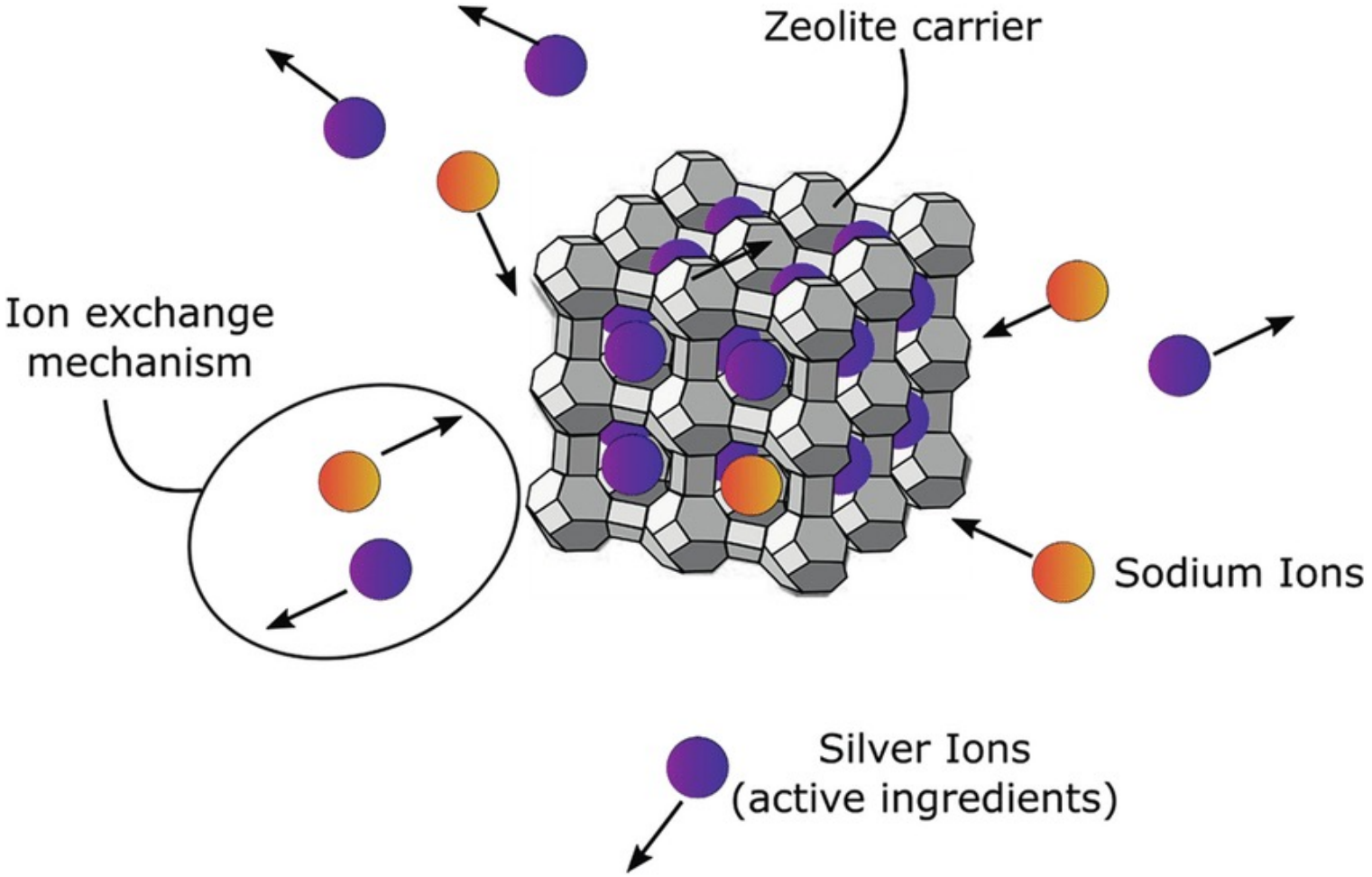
- Zeolites are microporous, aluminosilicate minerals commonly used as commercial adsorbents and catalysts.

- Mordenite is a zeolite mineral with the chemical formula, (Ca, Na_2, K_2) $Al_2Si_{10}O_{24}{\cdot}7H_2O$ and it is one of the six most abundant zeolites and is used commercially.

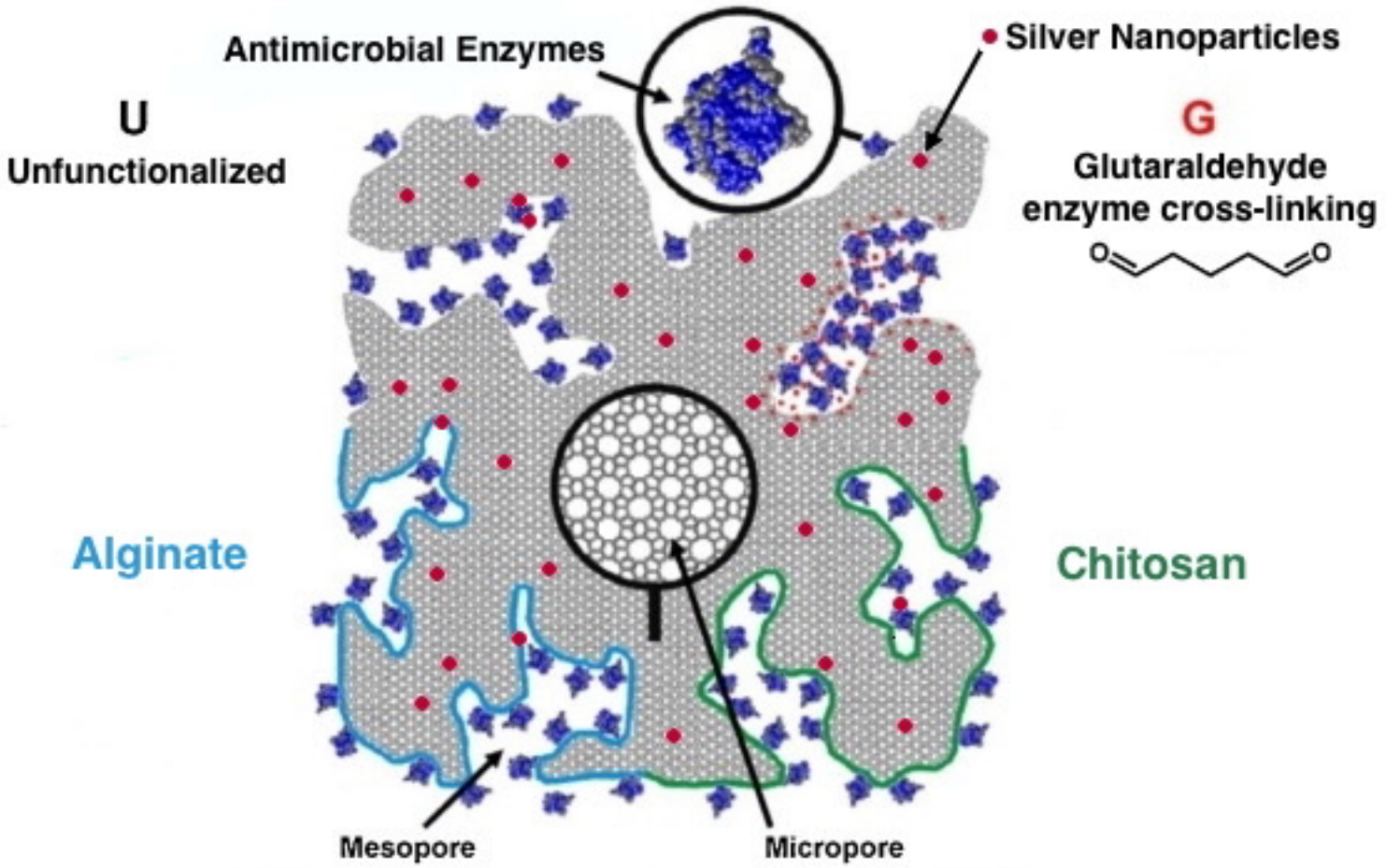




ZEOLITES


Zeolite carrier
Ion exchange mechanism
Sodium Ions
Silver Ions
(active ingredients)

AgNPs + Enzyme + Biopolymer in Zeolites

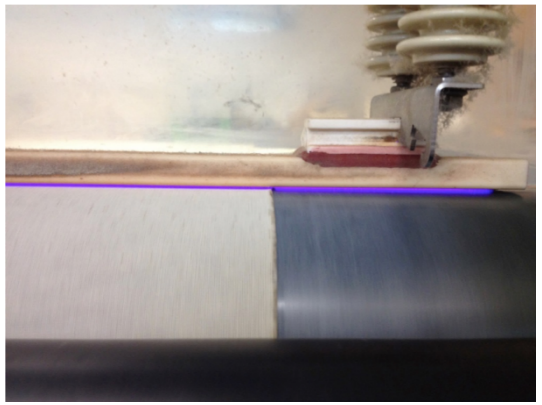


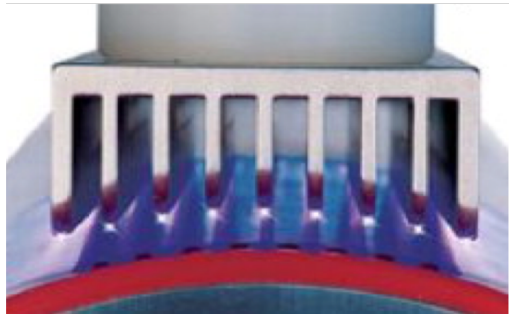
- **Protease** extracted from *Bacillus licheniformis*
- **Lysozyme** from chicken egg white (future work)
- **α-amylase** from *Bacillus spp.* (future work)

Substrates and Plasma

DOUBLE DIELETRIC DISCHARGE PLASMA

The applied power was between 4-15 kW and substrate (PES) pass velocity of 3 m min^{-1}

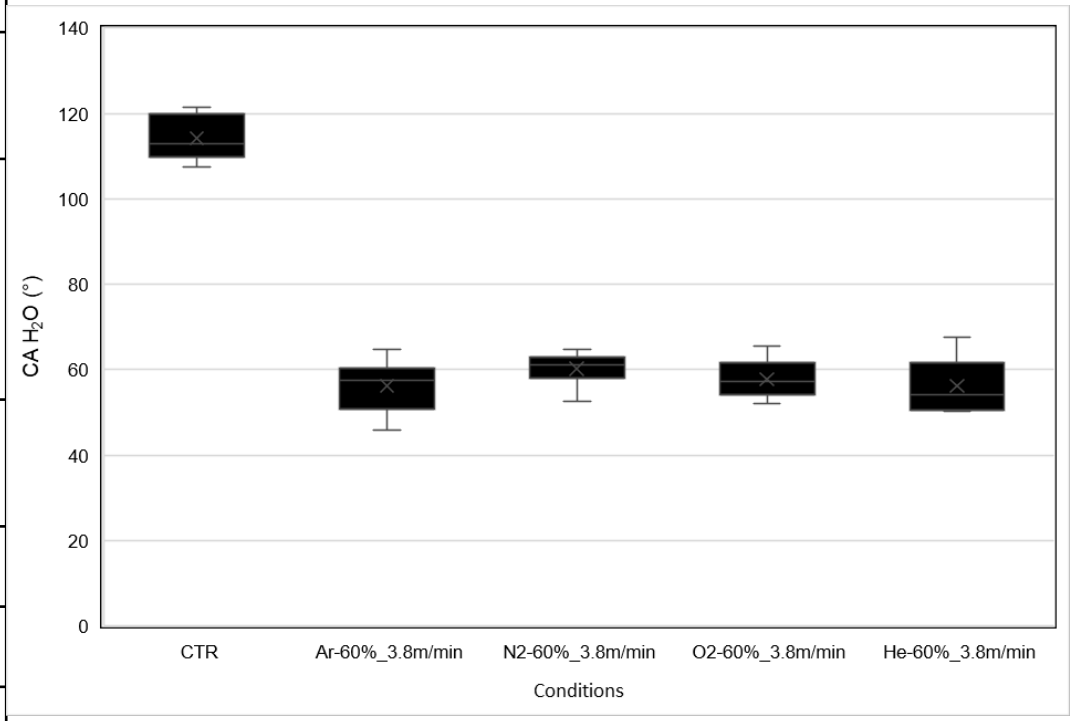




Substrates and Plasma

Contact angles with different gases and conditions

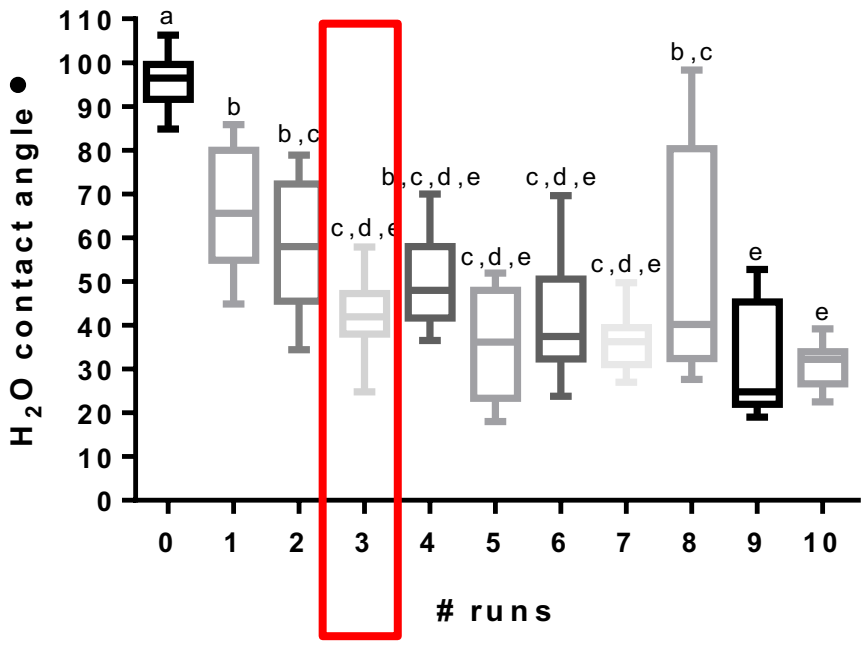
Nº	Gás	Power (%)	Velocity (m/min)	% Árgon	% Reactive gas
1	Ar (Corona)	100	3,8	-	-
2	Azoto	100	12	100	45
3	Oxigénio	100	7,7		
4	Hélio	60	3,8		
5	Ar (Corona)	60	3,8	-	-
6	Azoto	60	3,8	100	45
7	Oxigénio	60	3,8	100	45
8	Hélio	60	3,8	100	45

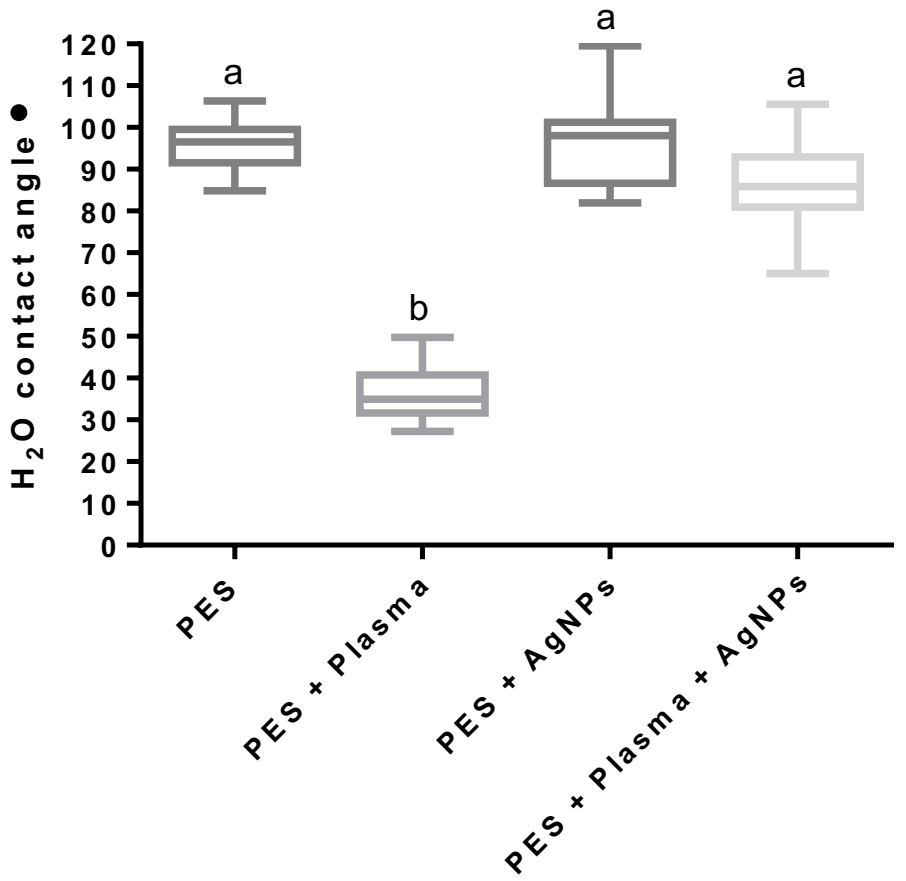


Substrates and Plasma

Contact angles with ceramic electrodes

Plasma conditions: Power: approx. 4 kW - Speed: 3.3 Hz





Substrates and Plasma

Contact Killing after plasma treatment with ceramics

Plasma conditions:

Power: approx. 4 kW - Speed: 3.3 Hz

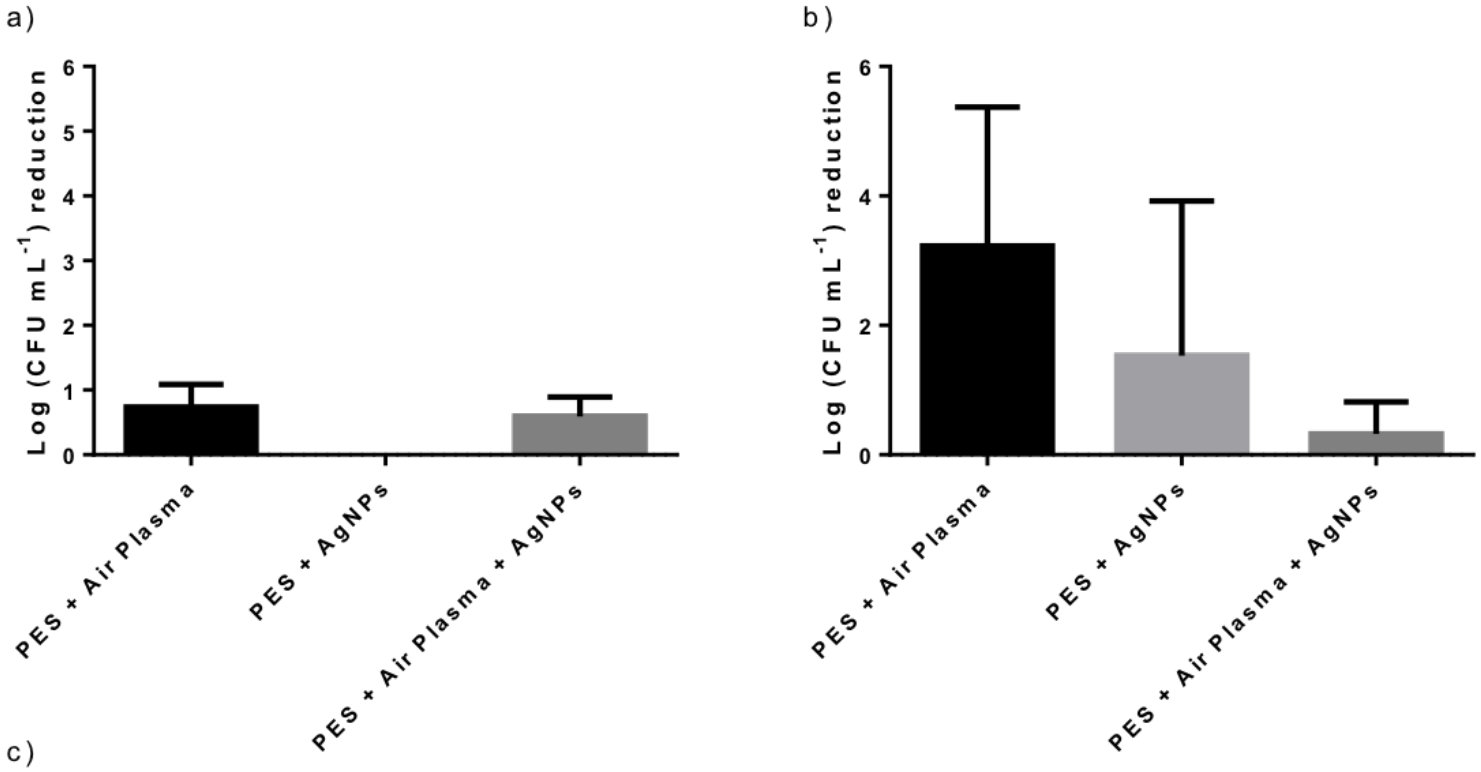
Contact conditions:

Contact time: 4 h

Bacteria:

a) S. aureus

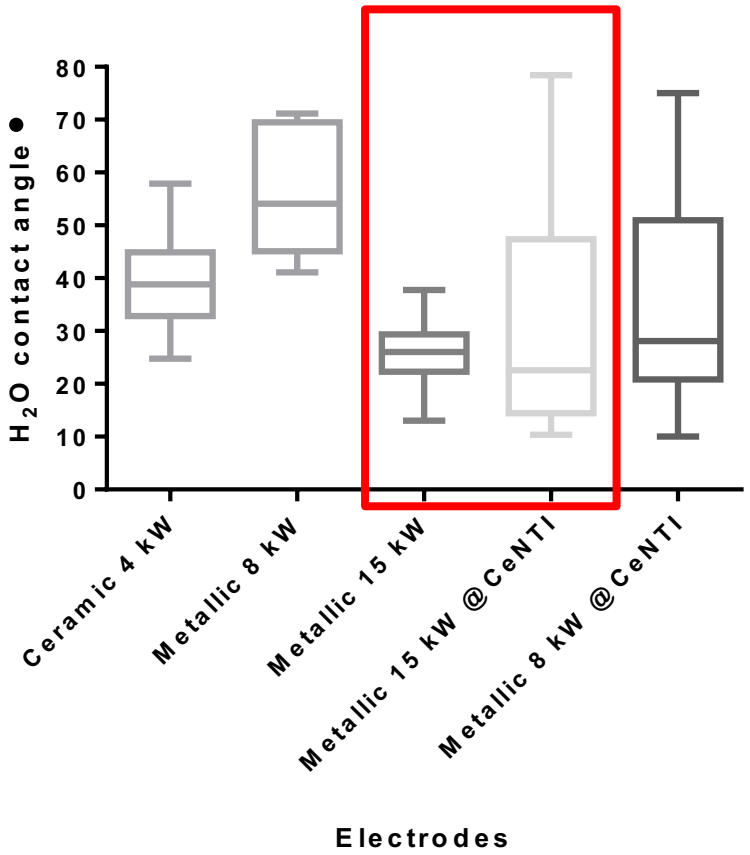
b) E. coli

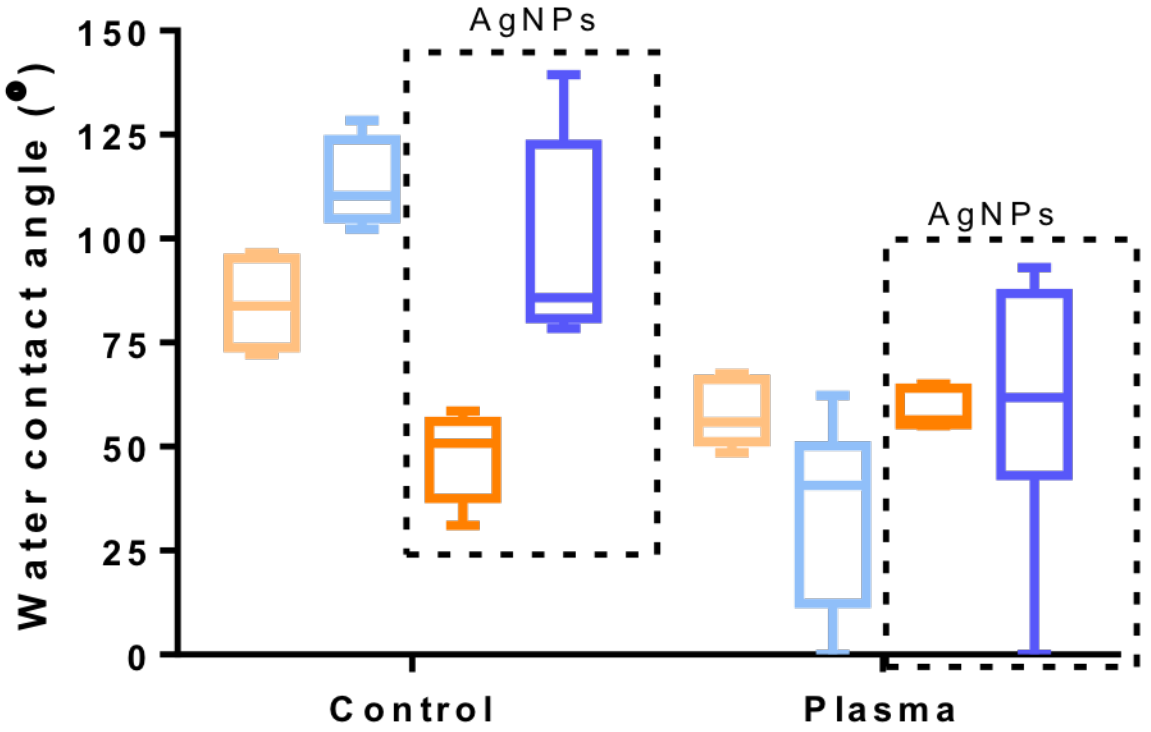


Substrates and Plasma

Contact angles with metallic electrodes

Plasma conditions: Power: 8 & 15 kW - Speed: 3.3 Hz





Substrates and Plasma

Contact Killing after plasma treatment with metals

Plasma conditions:

Power: approx. 8 & 15 kW - Speed: 3.3 Hz

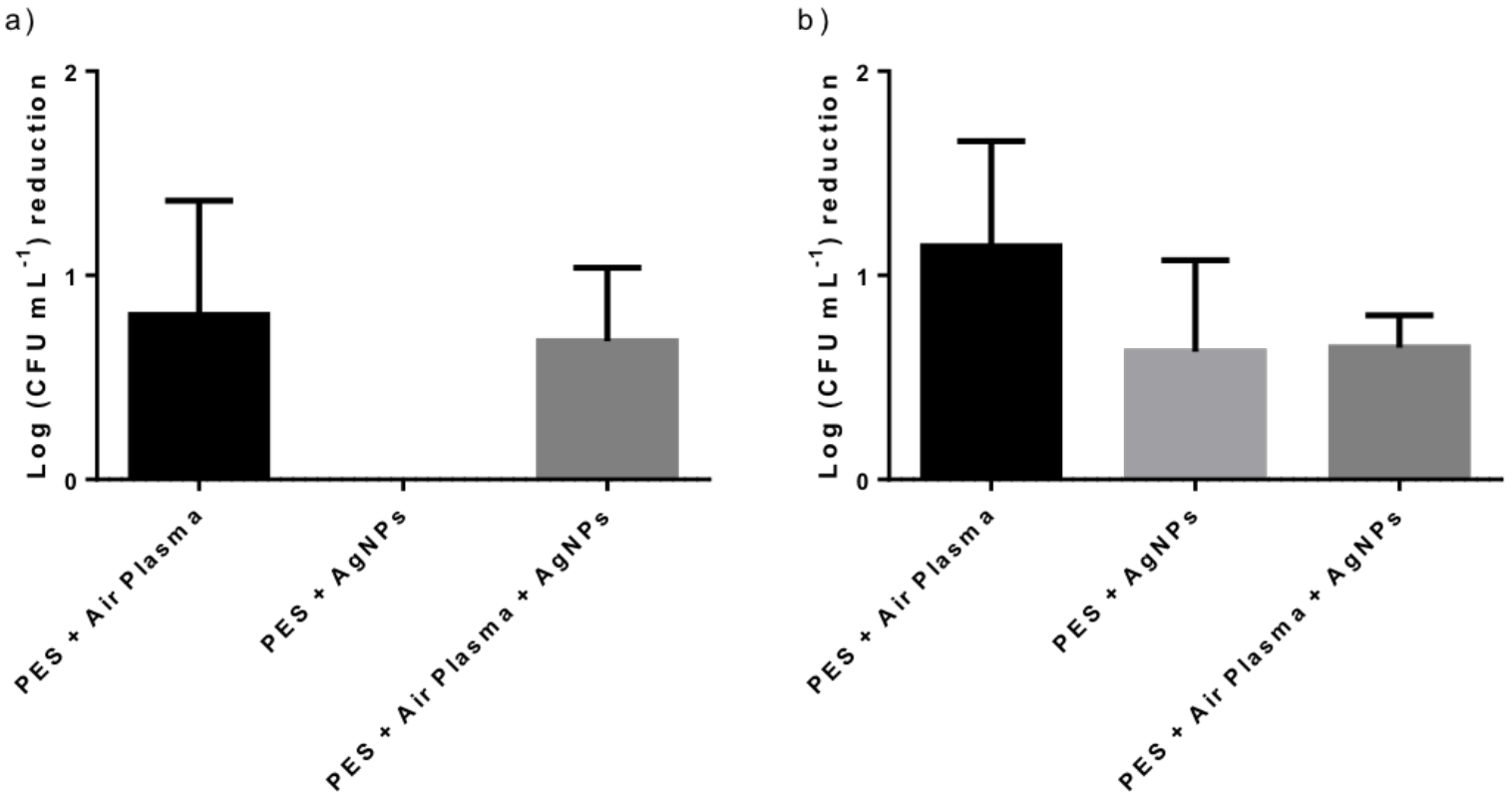
Contact conditions:

Contact time: 3 h

Bacteria:

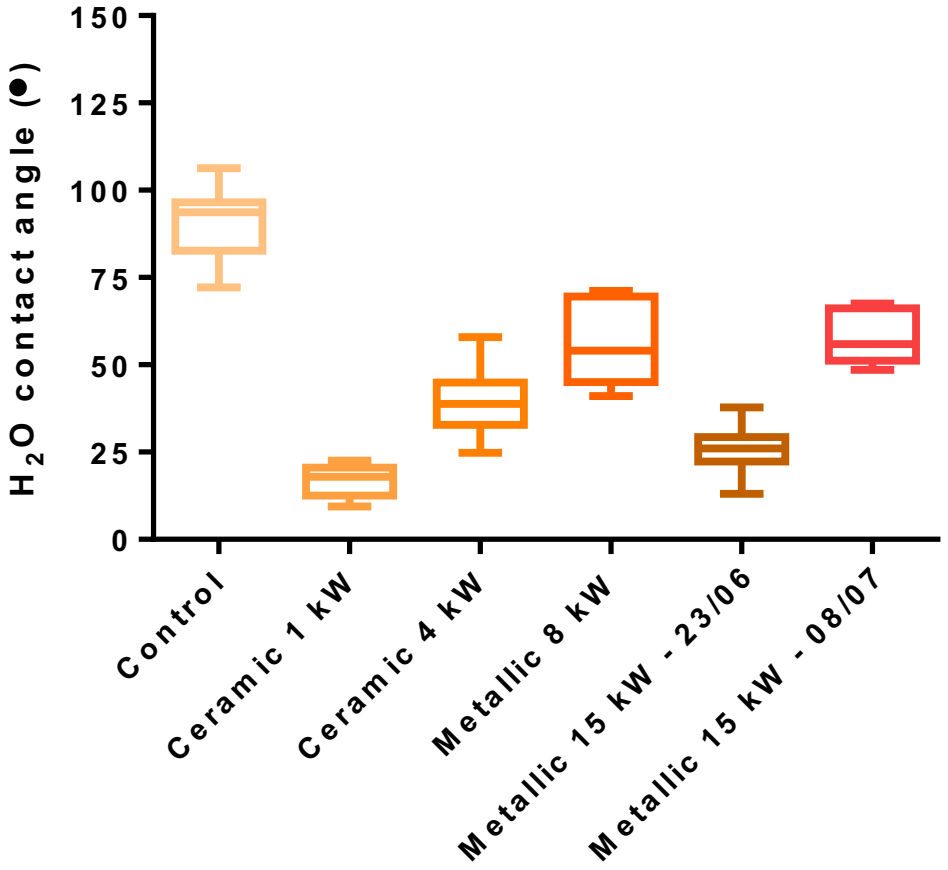
a) S. aureus

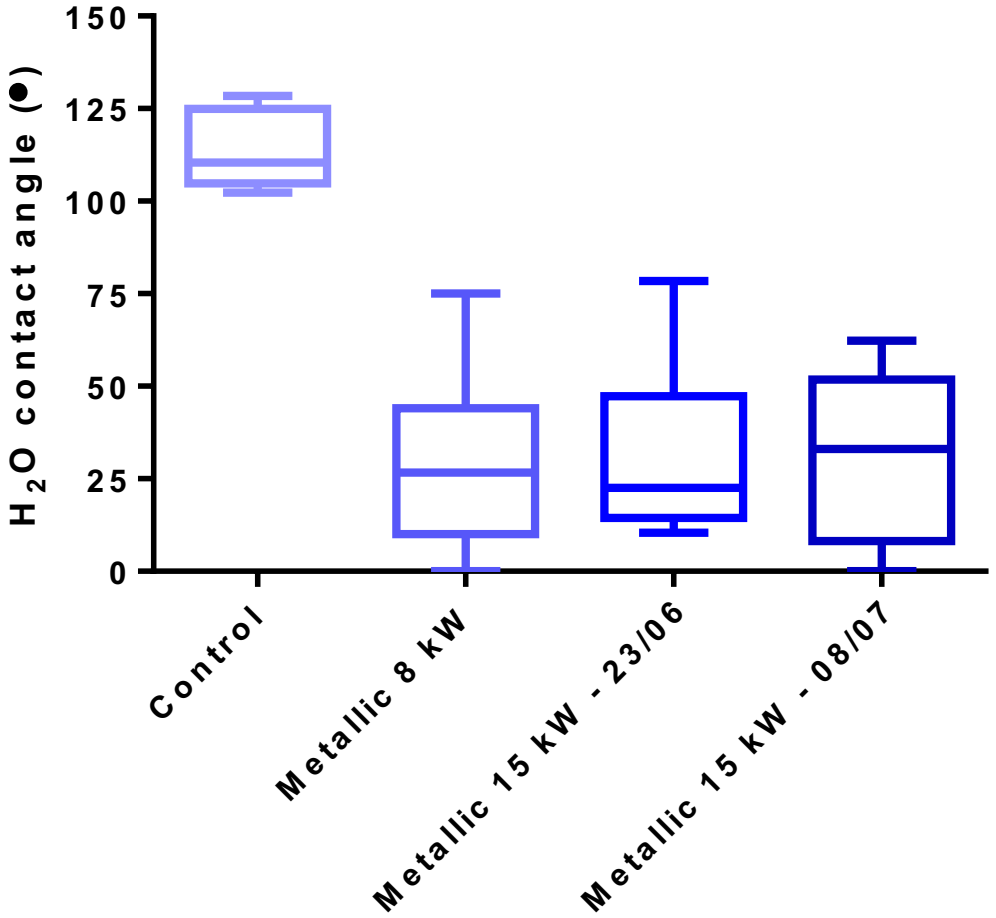
b) E. coli



Substrates and Plasma

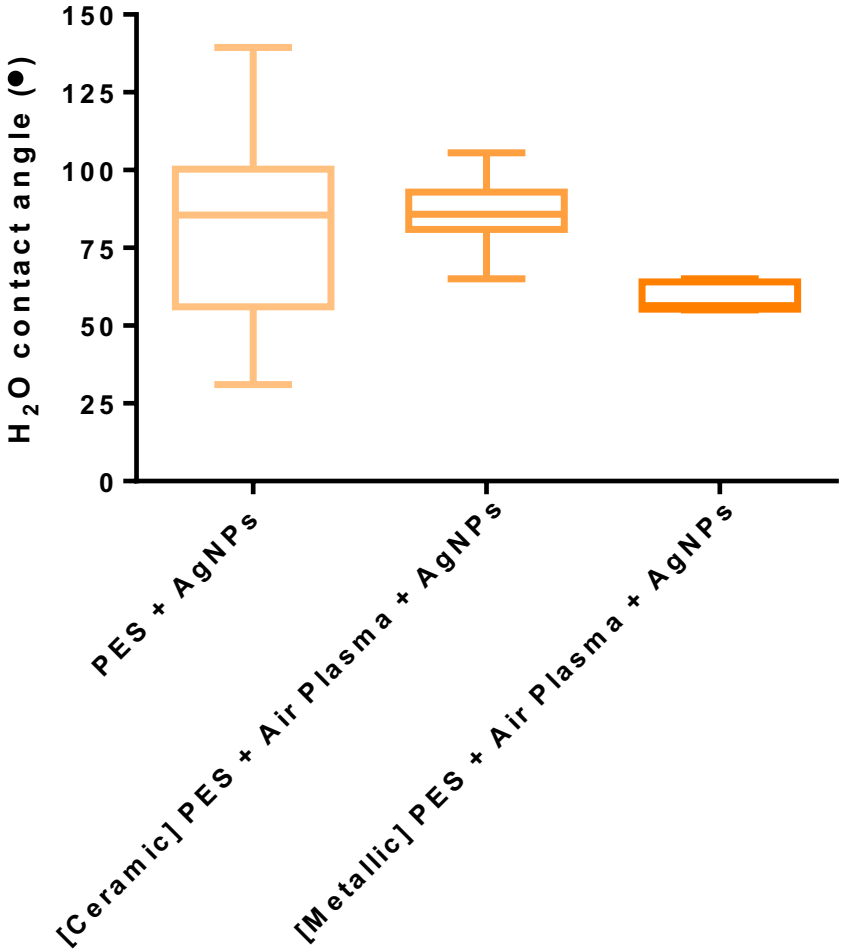
Contact angles with different electrodes - Overview

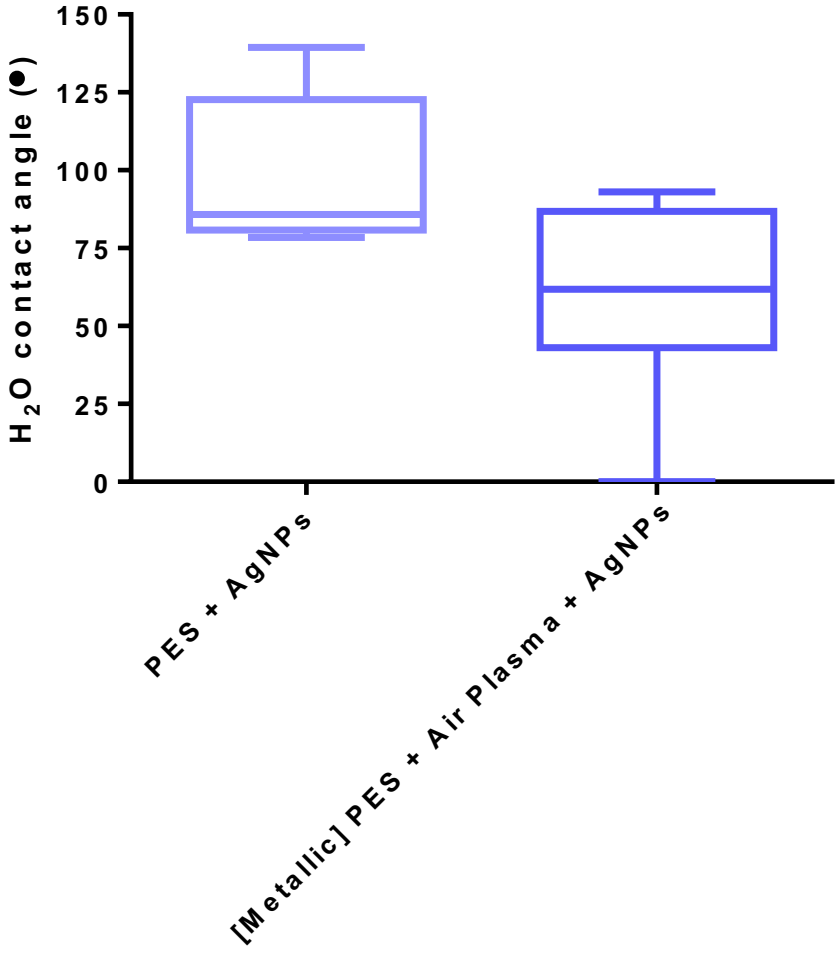




Substrates and Plasma

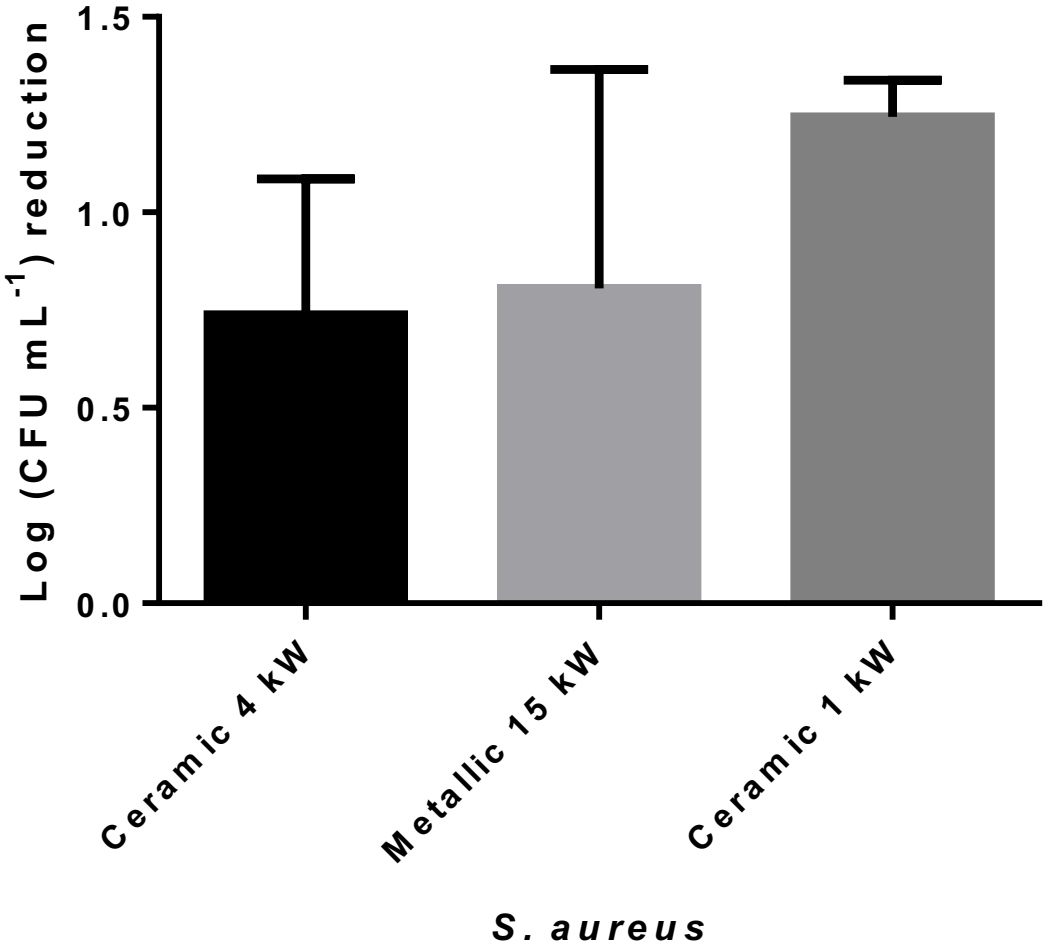
Contact angles with different electrodes - Overview





Substrates and Plasma

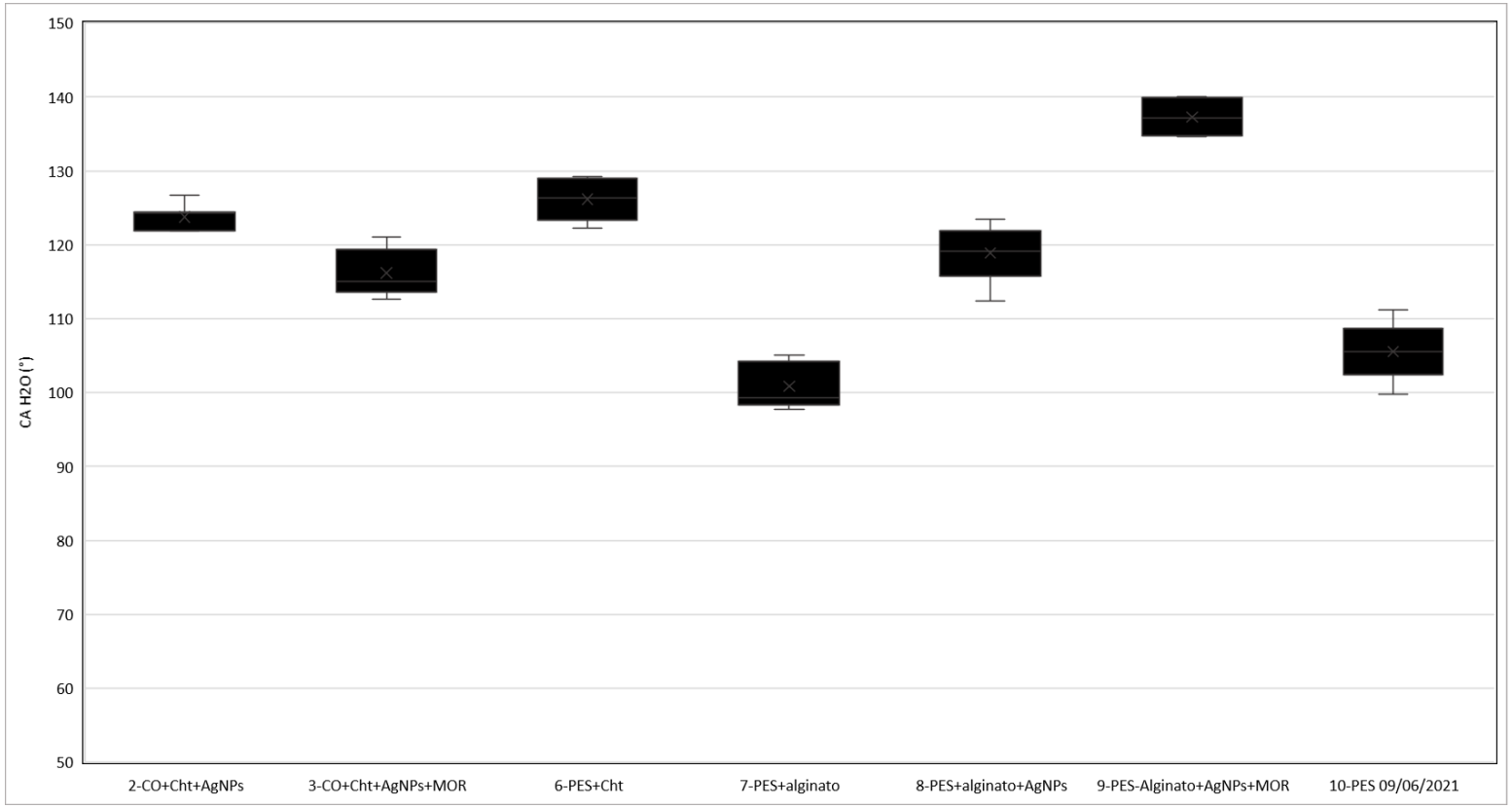
Contact Killing after plasma treatment



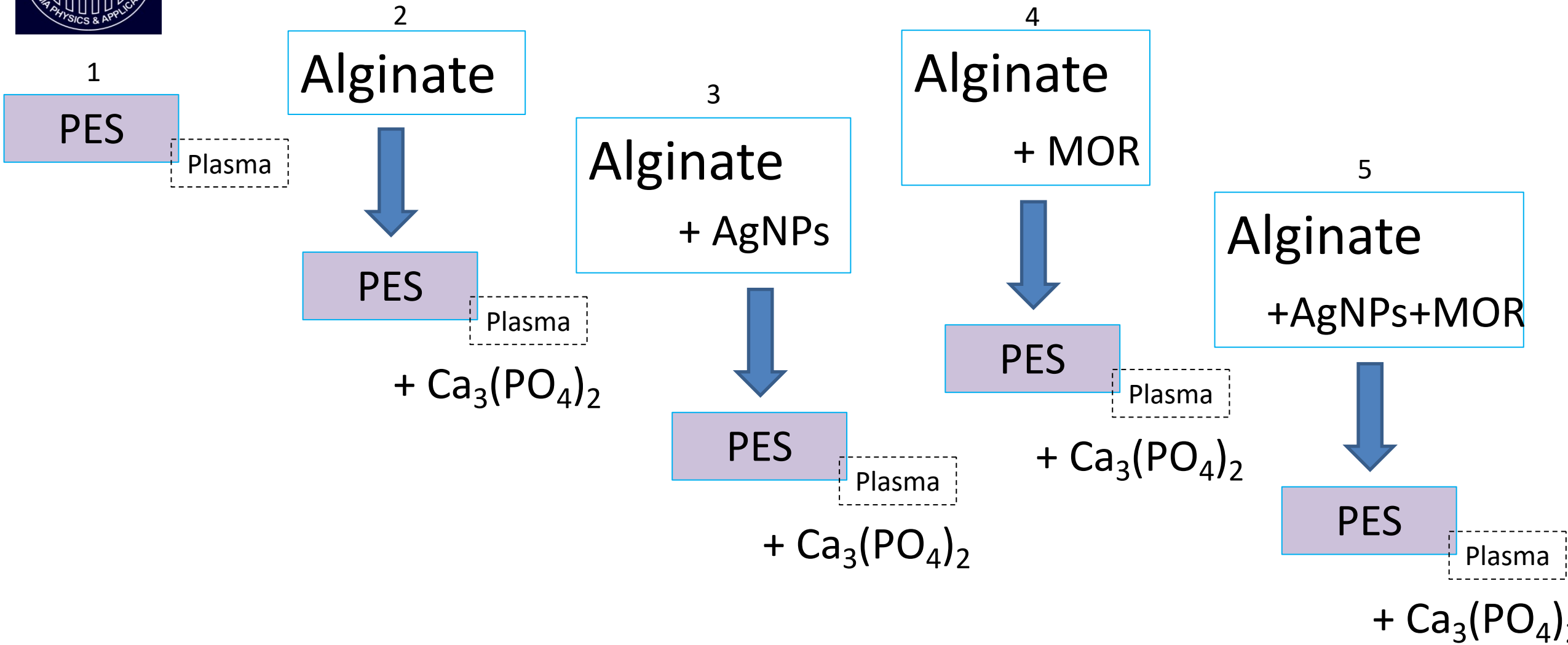
Substrates and Plasma

Contact angles after functionalization

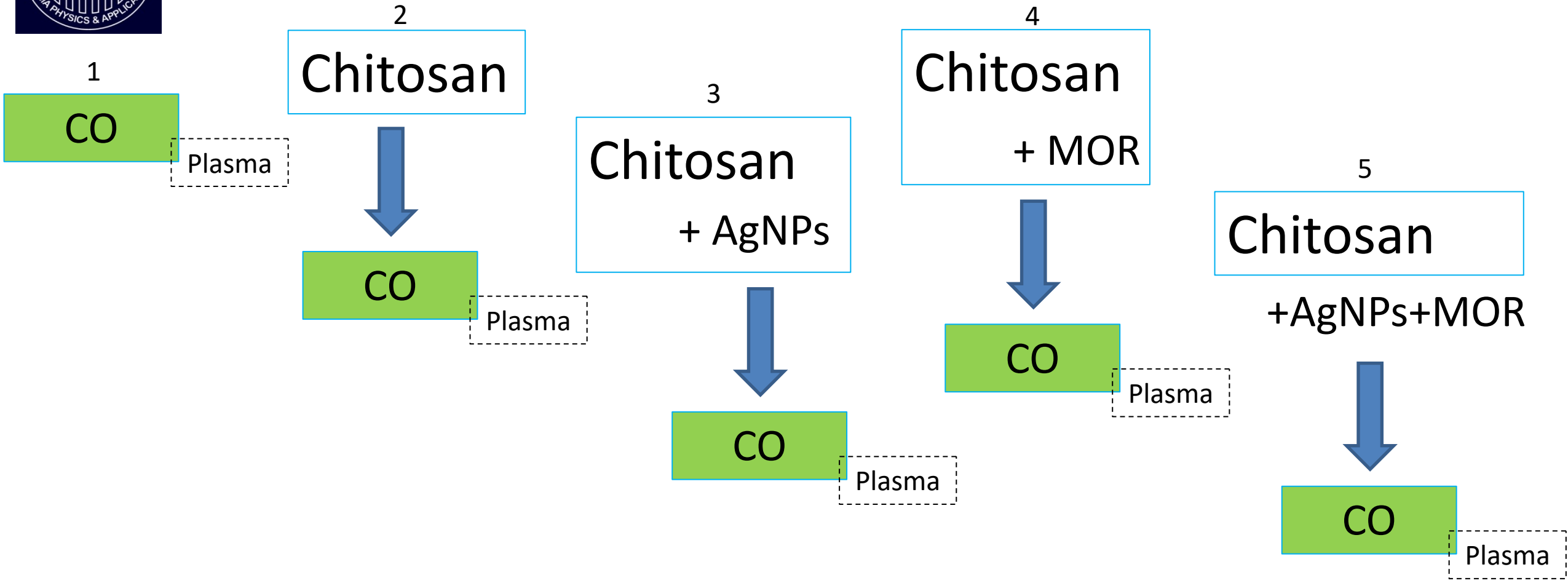
Nº	Descrição	CA H2O (º)
1	Cotton	n.d. (0)
2	CO+Cht+AgNPs	123,8±2,9
3	CO+Cht+AgNPs+MOR	116,2±2,9
4	CO+alginato+AgNPs+MOR	n.d. (0)
5	CO+Alginato+AgNPs	n.d. (0)
6	PES+Cht	126,19±2,6
7	PES+alginato	100,9±2,8
8	PES+alginato+AgNPs	118,9±3,6
9	PES-Alginato+AgNPs+MOR	137,3±2,5
10	PES 09/06	105,6±3,6



Mordenite with polymers and AgNPs



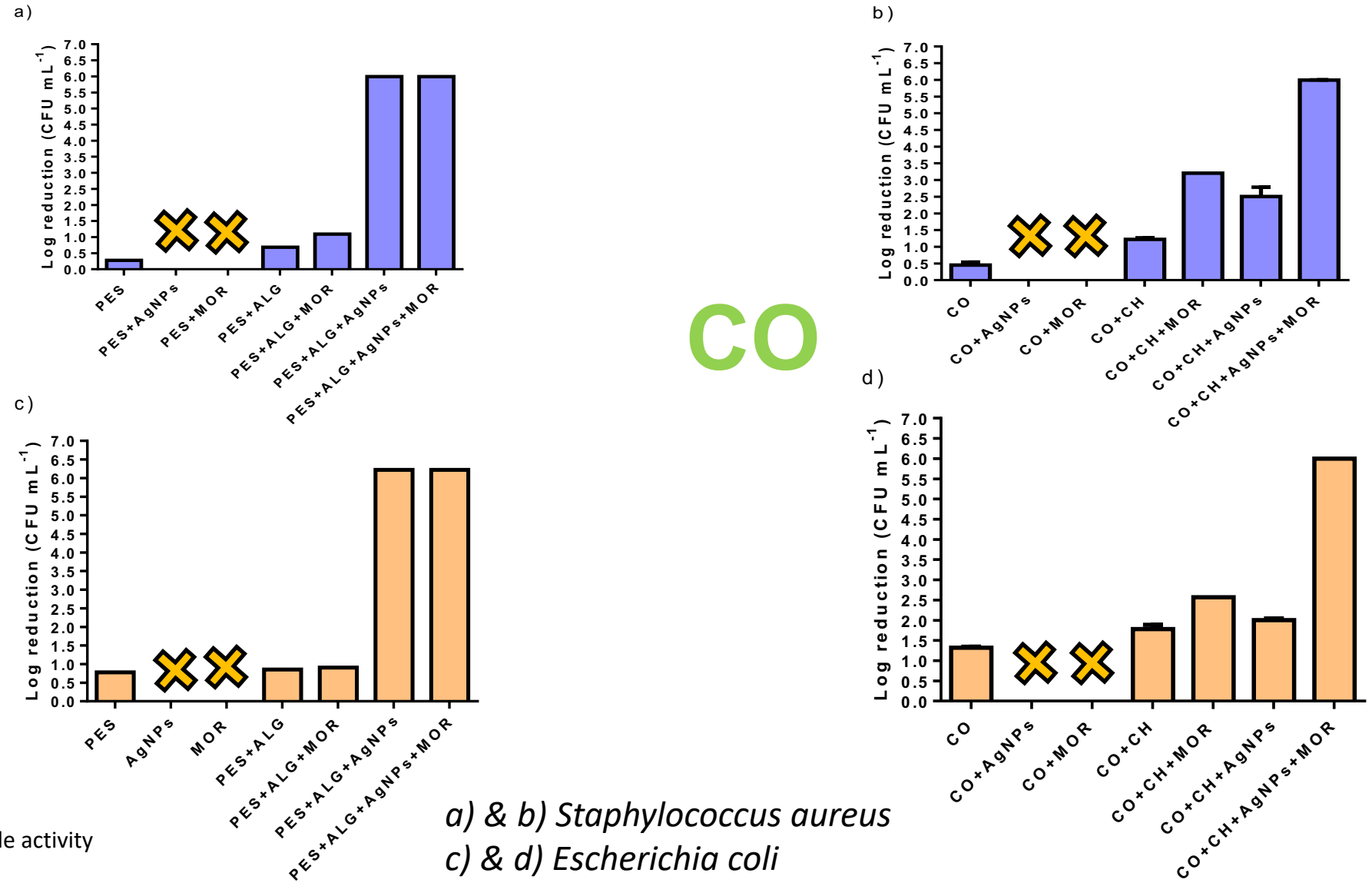
Mordenite with polymers and AgNPs



Mordenite with polymers and AgNPs

PES

CO



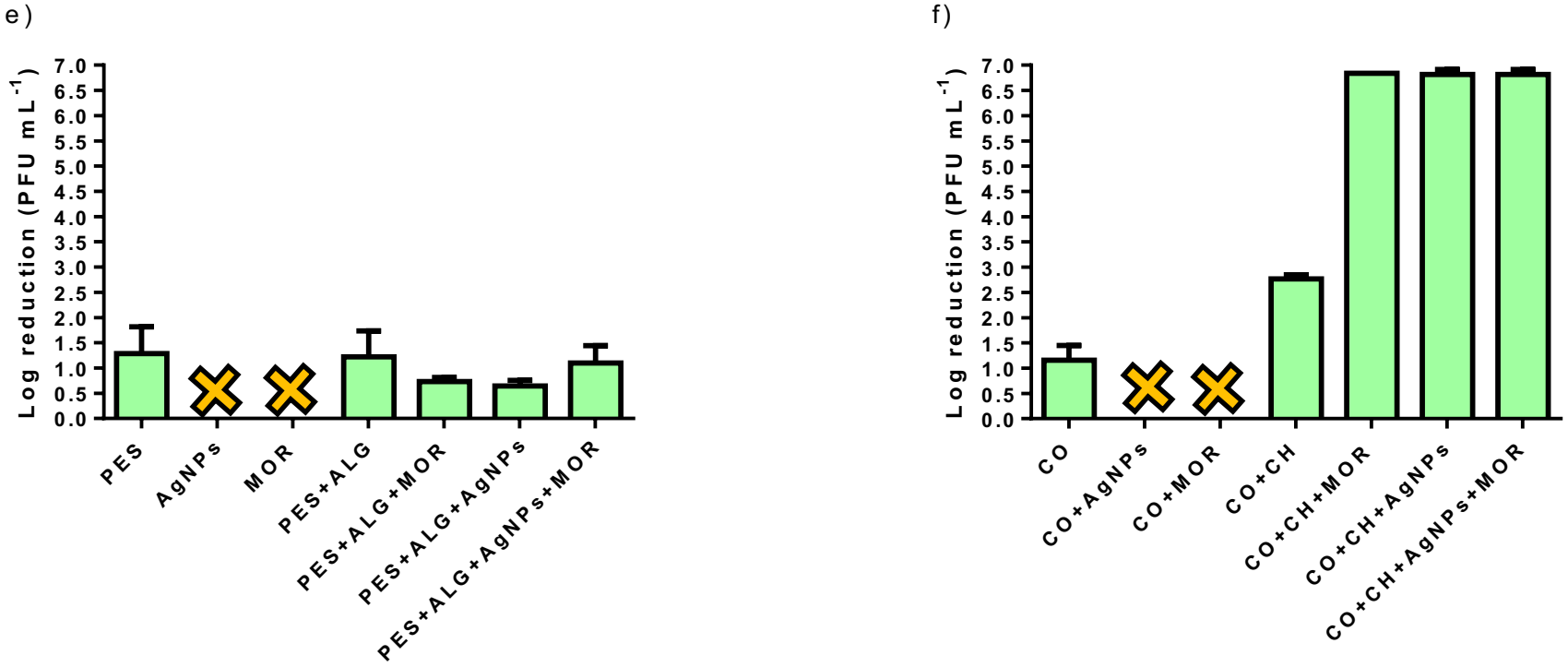
Missing or negligible activity

a) & b) Staphylococcus aureus
c) & d) Escherichia coli

Mordenite with polymers and AgNPs

PES

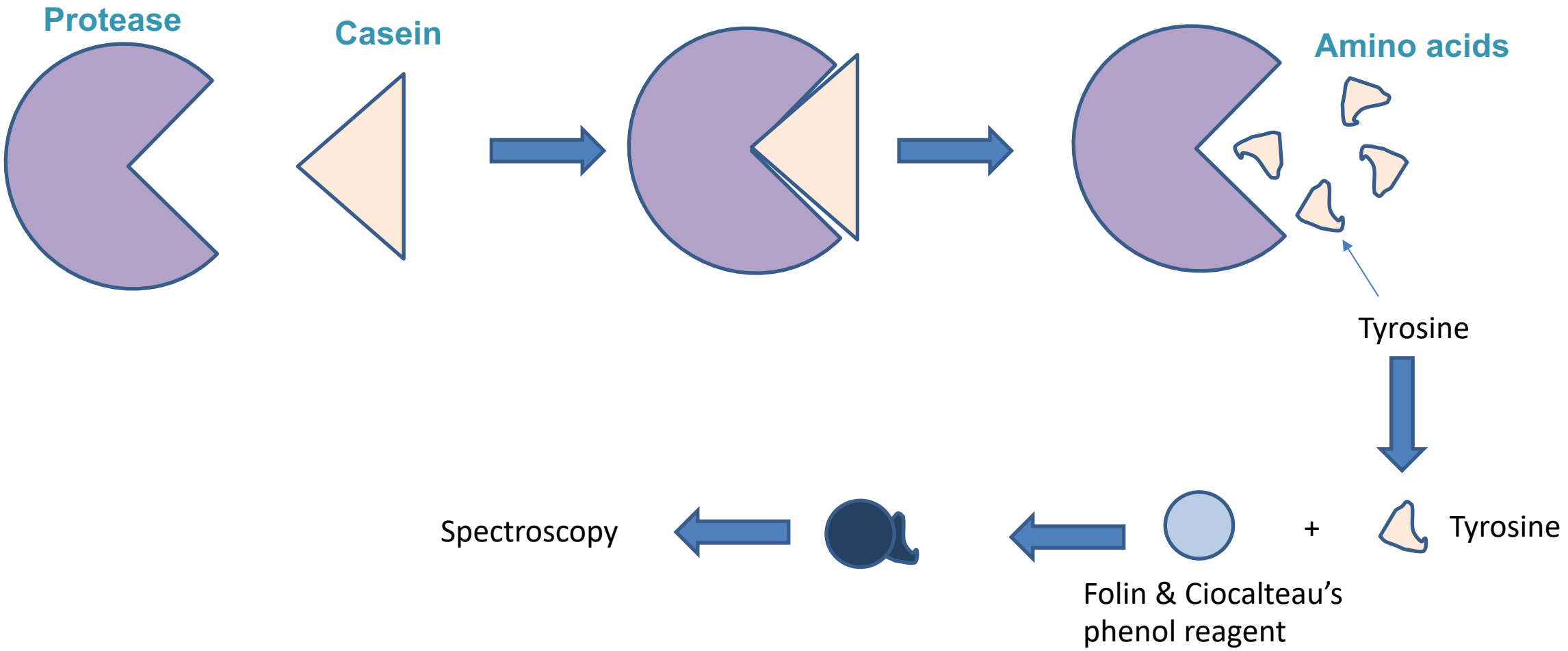
CO



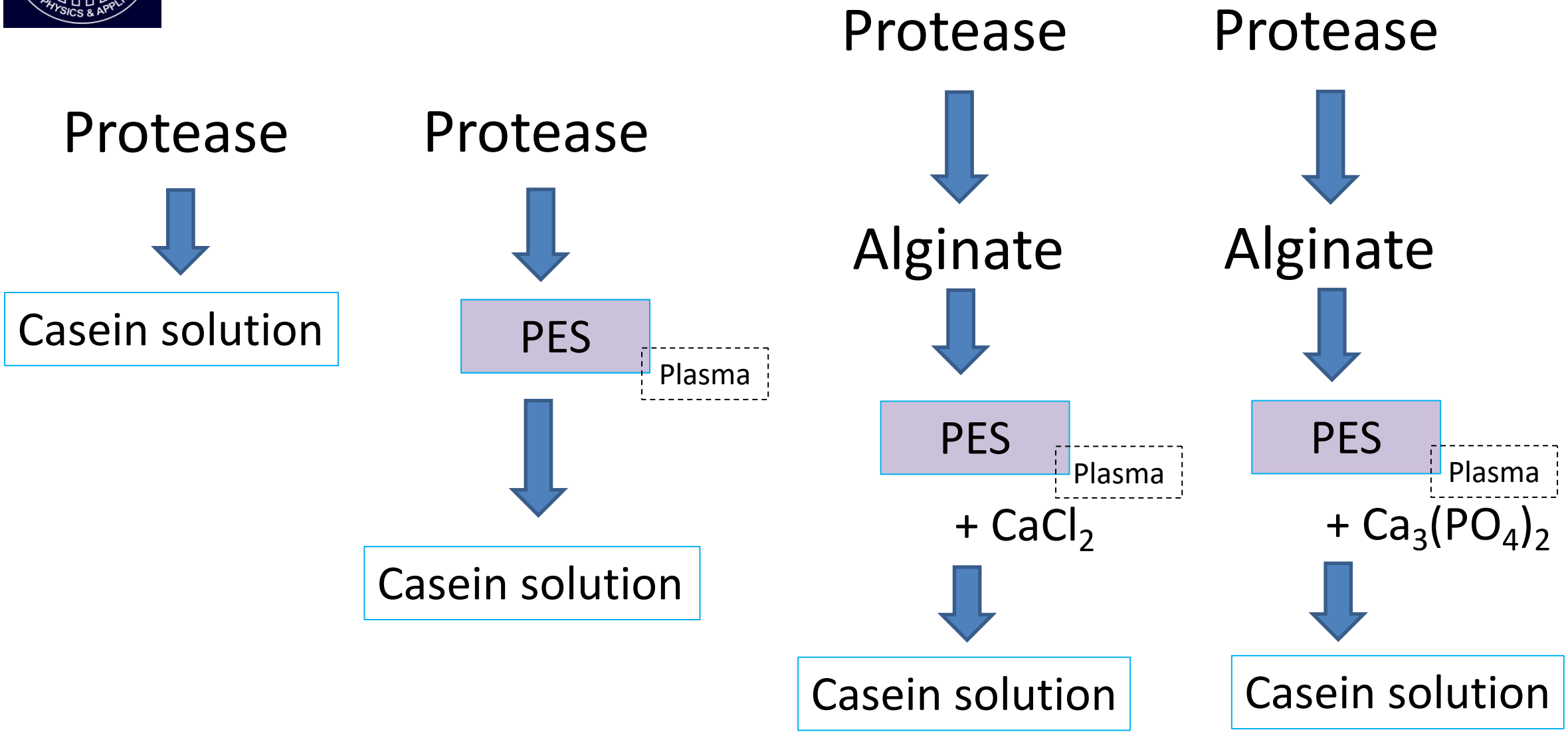
e) & f) MS2 bacteriophage

Missing or negligible activity

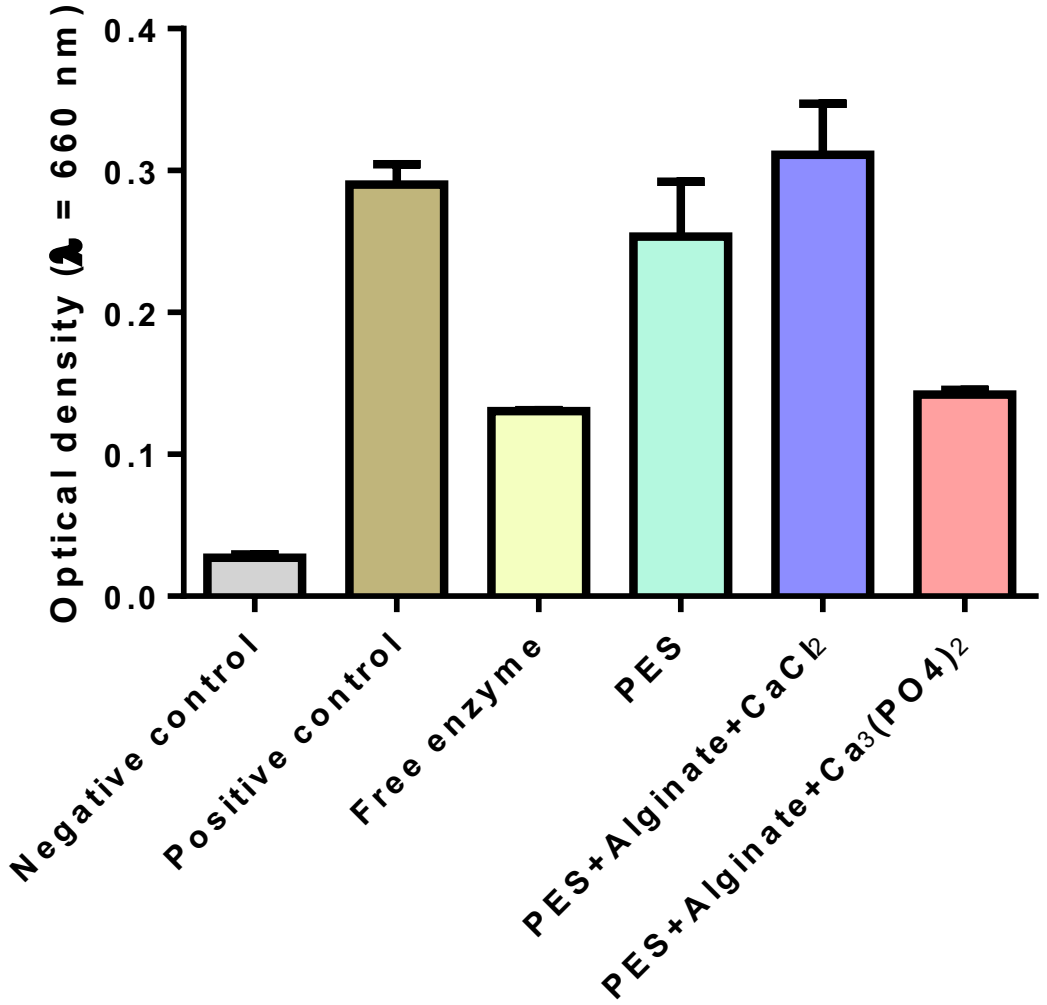
ENZYMES


Protease
Casein
Amino acids
Tyrosine
Tyrosine
+
Folin & Ciocalteau's phenol reagent
Spectroscopy

ENZYMES


Protease
Casein solution
Protease
PES
Plasma
Casein solution
Protease
Alginate
PES
Plasma
+ $CaCl_2$
Casein solution
Protease
Alginate
PES
Plasma
+ $Ca_3(PO_4)_2$
Casein solution

PES + Protease



PES + Protease

Protease

PES

Plasma

Protease

Alginate

PES + $Ca_3(PO_4)_2$

Plasma

Protease

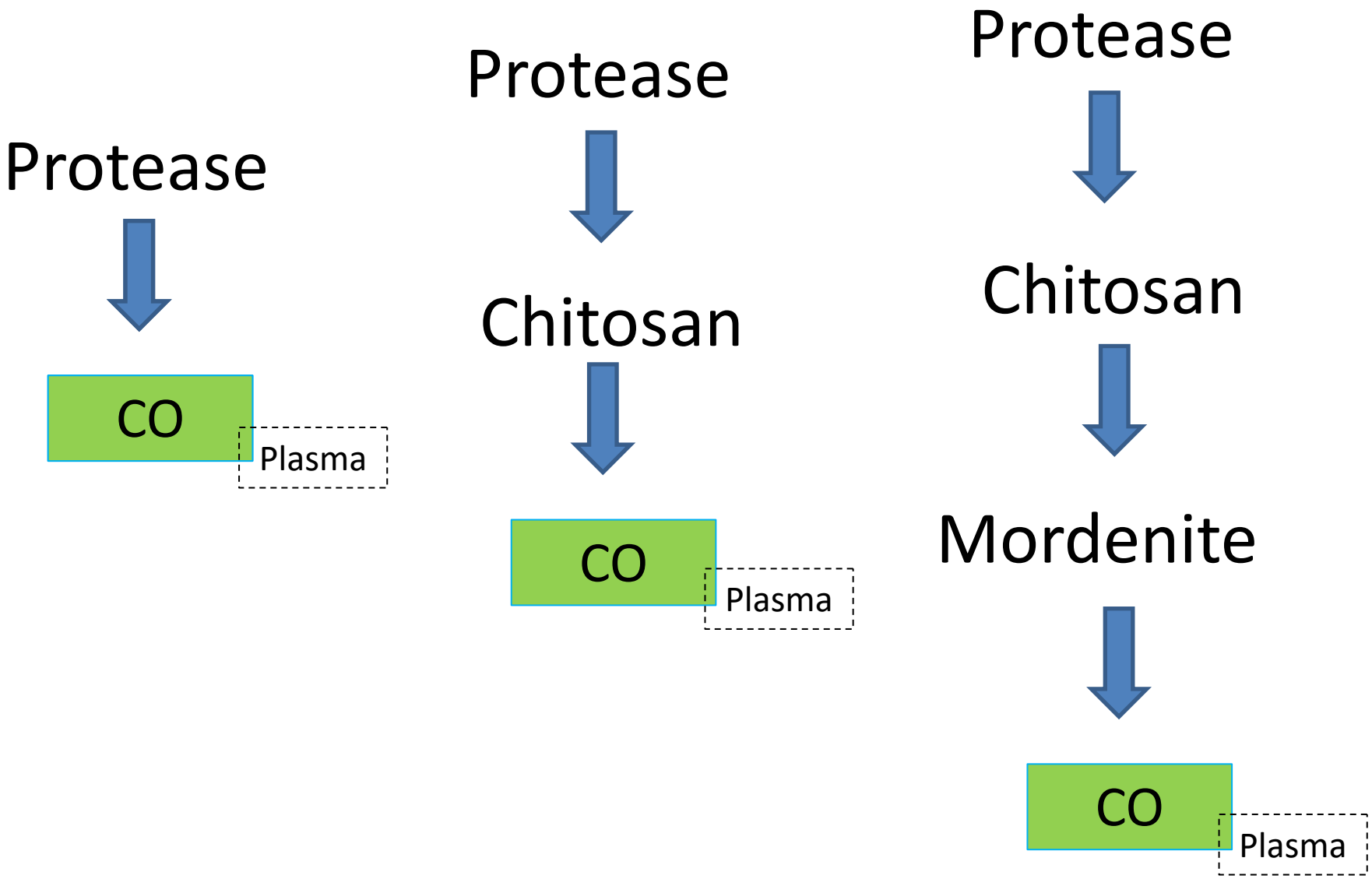
Alginate

Mordenite

PES + $Ca_3(PO_4)_2$

Plasma

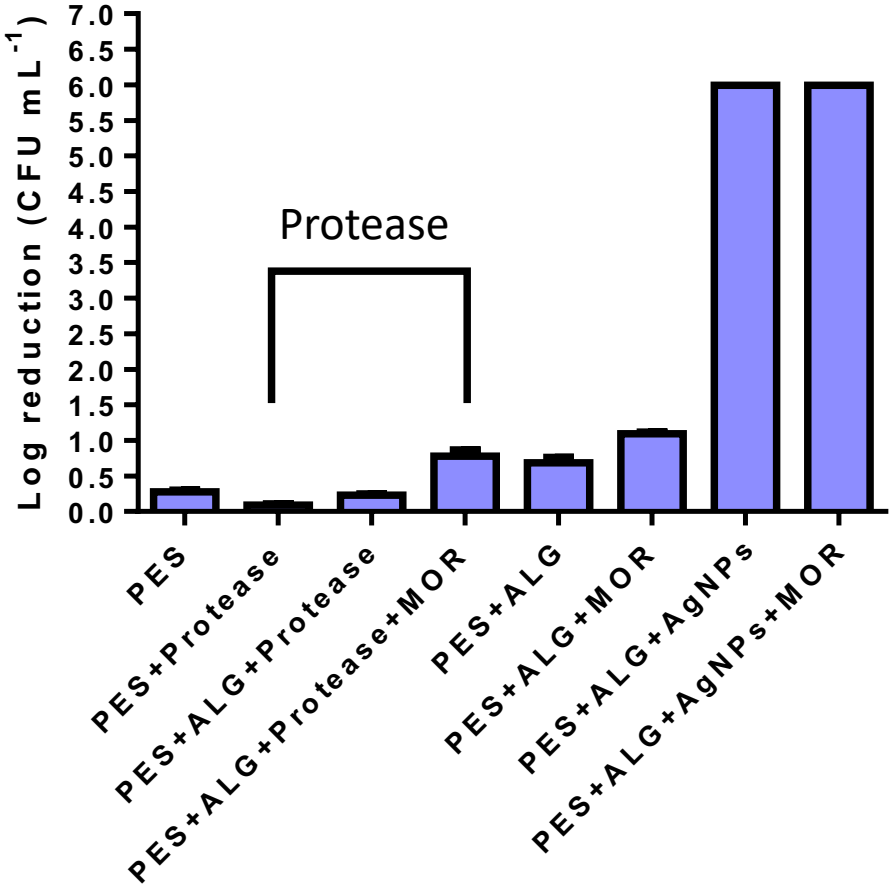
CO + Protease


Protease
CO
Plasma
Protease
Chitosan
CO
Plasma
Protease
Chitosan
Mordenite
CO
Plasma

Staphylococcus aureus

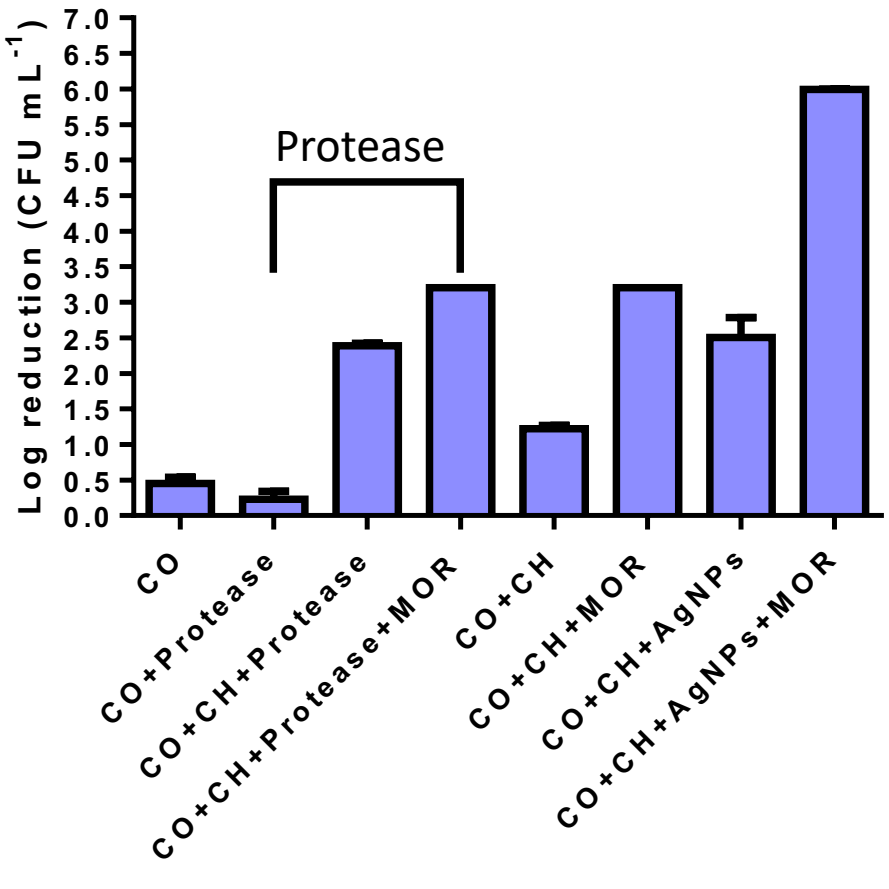
PES

a)



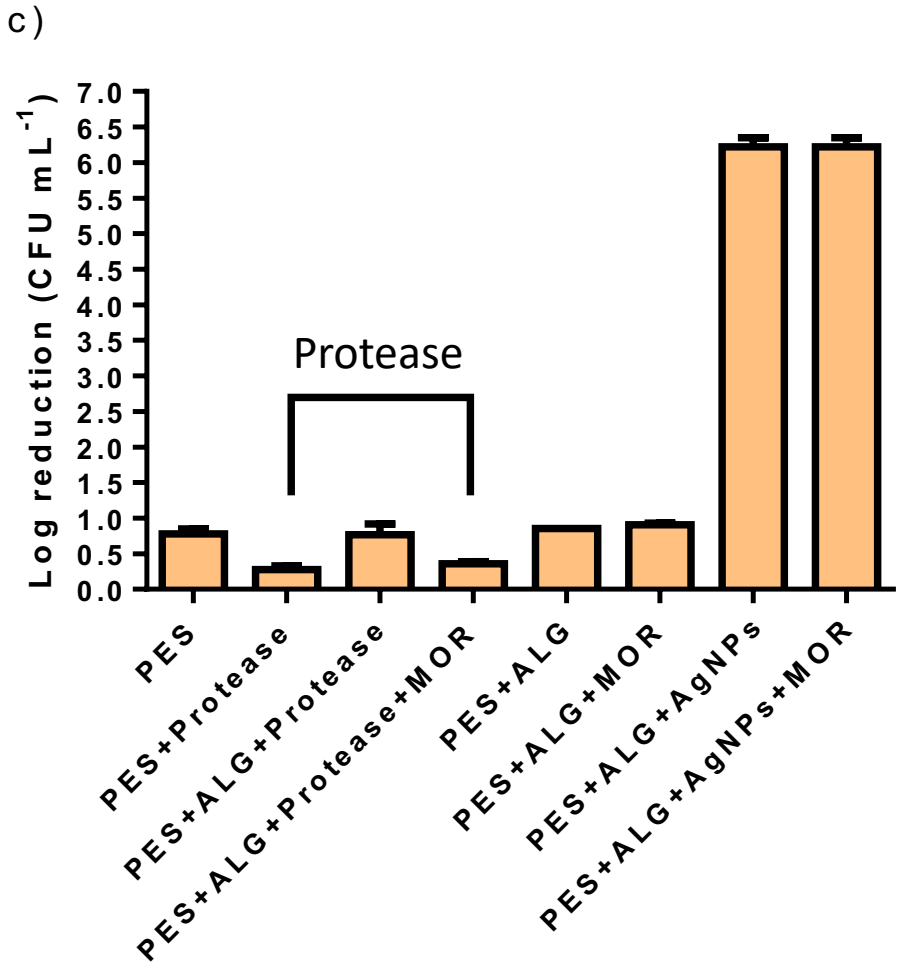
CO

b)

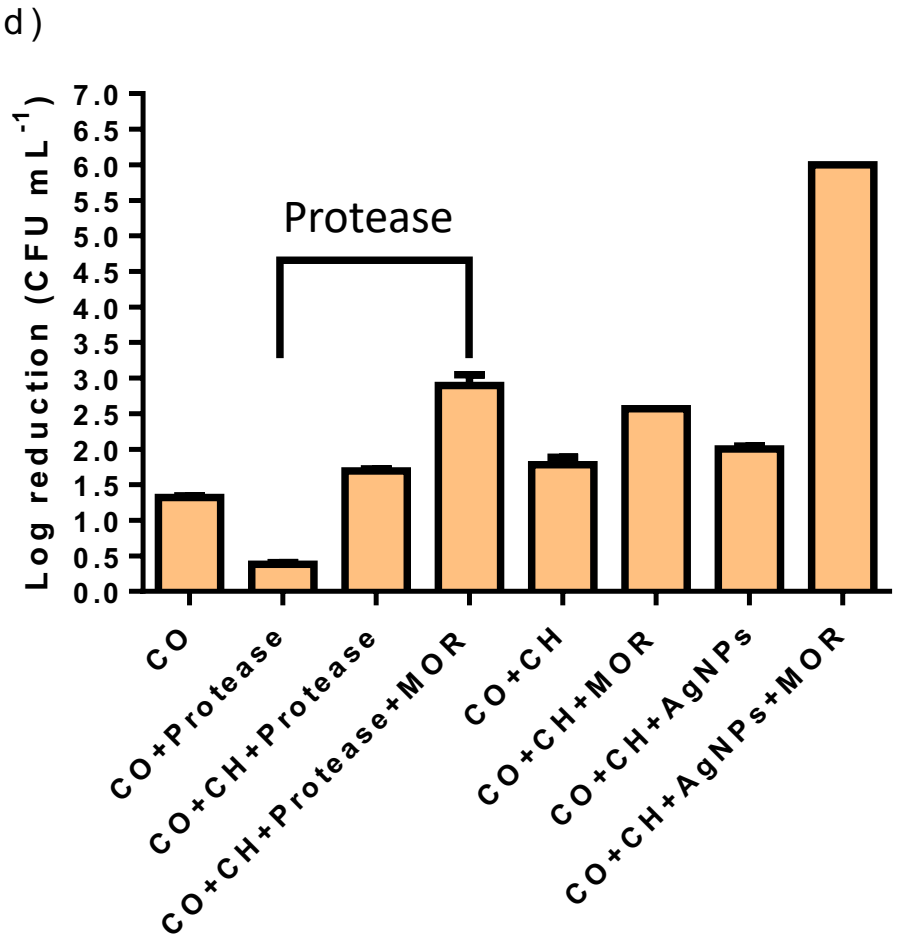


Escherichia coli

PES

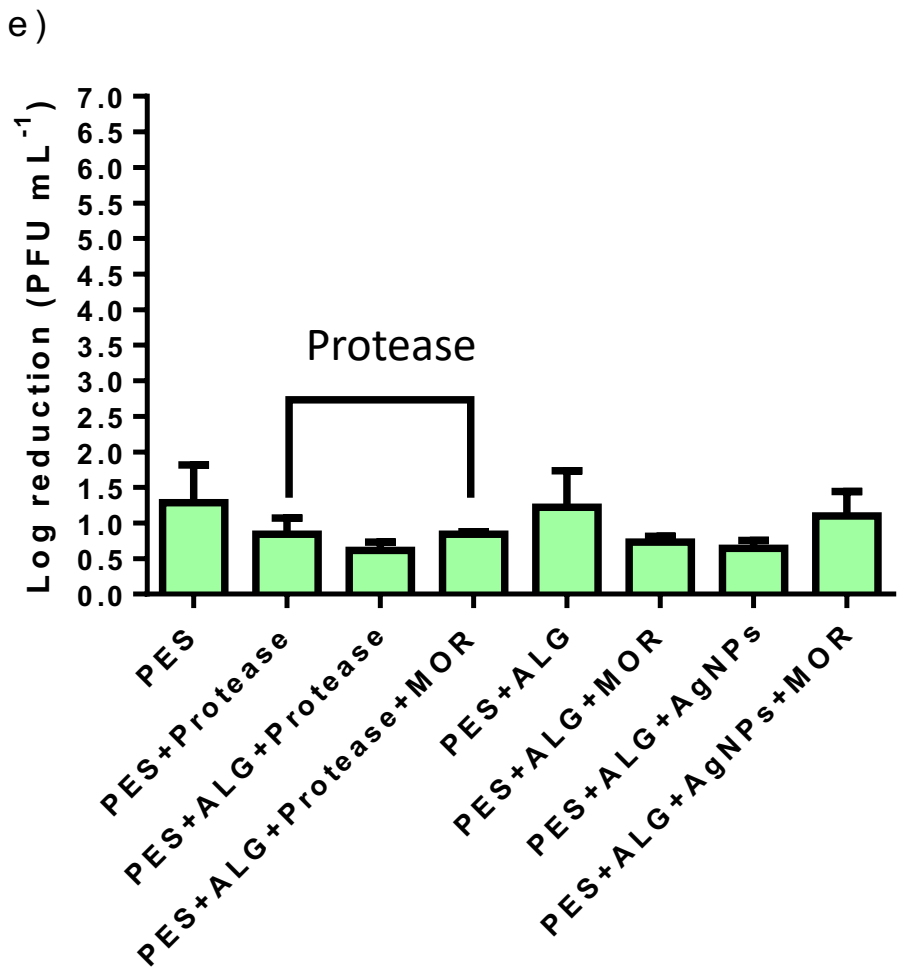


CO

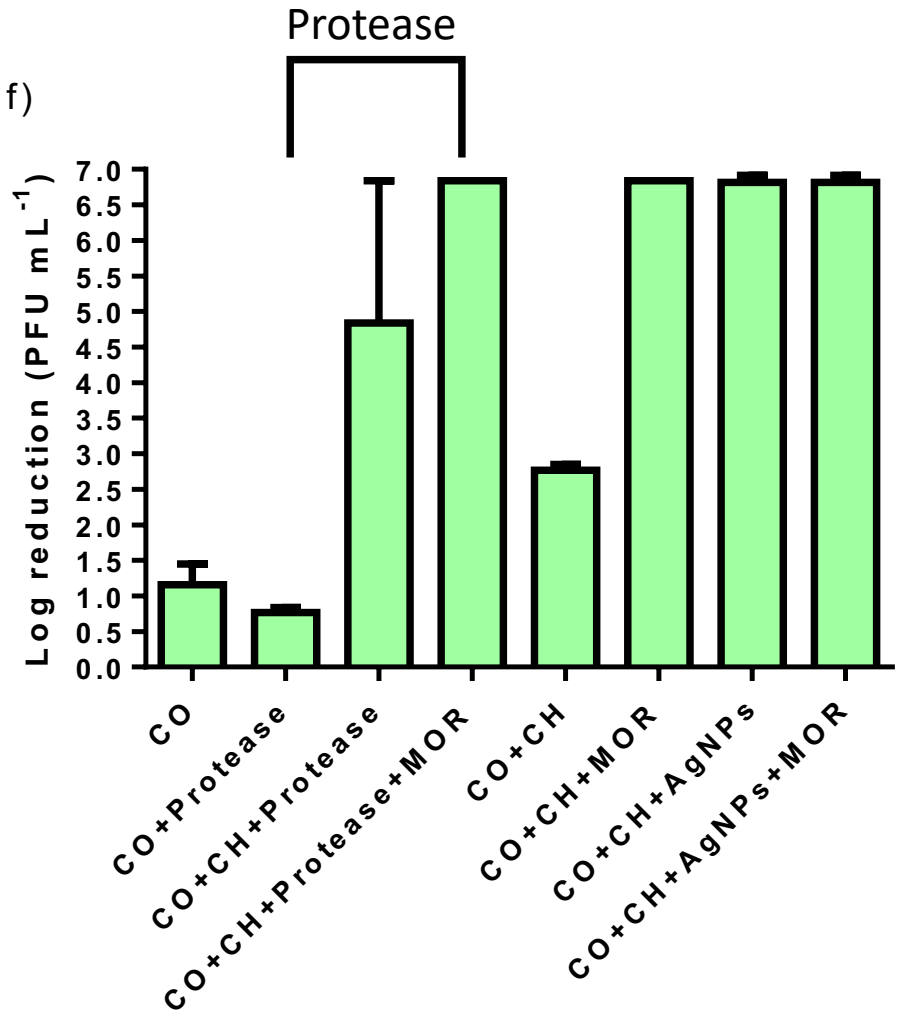


MS2 bacteriophage

PES



CO



Acknowledgments

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19th CONFERENCE
August 31-September 3, 2021
Magurele - Bucharest
ROMANIA
PLASMA PHYSICS & APPLICATIONS

CENTRO DE CIÊNCIA E TECNOLOGIA TÊXTIL

Universidade do Minho
Escola de Engenharia

Thank you for your attention!

COMPETE
PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE

QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
PORTUGAL 2007.2013

UNIÃO EUROPEIA
Fundo Europeu de Desenvolvimento Regional

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA